Artificial Intelligence Techniques for Pilot Approach Decision Aid Logic (PADAL) System

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13. ABSTRACT *(Maximum 200 words)*

In this project the objective was to improve Landing Signal Officer (LSO) decision making by using Artificial Intelligence (AI) and other techniques to develop pilot trending and ship oscillation decision support aids. During the pursuit and satisfaction of the primary objective, several sub-objectives were met. The project developed pilot trending and ship oscillation recognition techniques and software by investigating the use of Fourier, wavelet, neural networks, fuzzy logic and other transform techniques in conjunction with the application of decision-centered design methodologies from cognitive psychology; the research determined that a combination of neural networks and fuzzy logic applied under a decision-centered design approach proved most useful and was developed. We determined the significant aircraft approach parameters and similarity measures and important pilot considerations and similarity measures. We also developed pilot trending techniques and software using case-based reasoning and combinations of other AI techniques. In addition, in conjunction with many LSOs, we determined the best display options and most appropriate display logic for the information produced by the pilot trending and oscillation recognition modules, and designed and implemented the resulting LSO interface. Then the design concepts were implemented and tested, in an iterative fashion. The decision aid prototypes were evaluated and critiqued by active LSOs with enhancements based on feedback from the LSOs.

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1 Executive Summary

This report summarizes the work performed during this Phase II Small Business Innovation Research (SBIR) project. All objectives stated in the Phase II proposal were accomplished. Furthermore, Klein Associates, Inc, the primary sub-contractor on the effort, along with the SHAI team engaged in significant interaction with LSOs, which was, and will be, incredibly important for this effort.

2 Problem Statement

The Aircraft Carrier, or CV, landing environment is an extremely complex one. In addition to operating what may be termed as an extremely busy airport, CV landing operations are affected by a number of variables not associated with a normal aerodrome. Of these, the most critical are fleet tactical considerations, flight deck space constraints, CV maneuvering space (sea room), flight deck motion (pitch and roll), continuous mechanical preparations, resetting arresting gear and optical landing system between each landing, airborne aircraft fuel status and management of aerial refueling assets, aircraft ordinance, minimal use of navigation, communications and radar emissions as in EMCON operations and, above all, time constraints.

Safe and efficient control of this environment requires following a strict chain of command and adhering to a set of standard operating procedures. The chain of command follows from the CV Captain, through the Air Operations Officer (Airops), below the flight deck, and the Air Officer (Air Boss), in the tower, to the Landing Signal Officer (LSO), stationed at the stern of the ship next to the landing area. The Captain is ultimately responsible for the entire operation of his ship. The Airops Officer is responsible for aircraft outside a five mile radius to a distance of twenty miles from the ship, as well as managing airborne fuel/aerial refueling and aircraft status and providing surveillance and precision radar guidance to the pilots for both night and low visibility approaches and landings. The Air Boss is responsible for aircraft within five nautical miles as well as all flight deck preparations, aircraft handling on the flight deck, and final landing clearance. The LSO is responsible for the aircraft's final approach and landing.

During the last 60 seconds, the cognitive demands, namely the critical decisions and judgments, increase quickly until a decision to wave off, or not, is made. Day landings with good weather are ideal conditions, but unfortunately not all days, or nights, are like that. Often times the ship is heaving 10 ft. up and 10 ft. down, making a 20 ft. displacement from a level deck. In addition, it is often difficult to see the aircraft approach during night operations, and impossible to see during stormy conditions at night. The LSOs must rely on auditory cues and the equipment at the LSO station to assist their decision making. For this project, we were tasked to design a decision support tool that will assist LSO decision making and hopefully increase the amount of time to make a wave-off decision, which is usually about 0.5-4 seconds. The focus of the decision support tool was to provide pilot trending information along with key oscillation deviations so that the LSO could improve both safety and efficiency of recoveries. We feel that we have done this with our current interface, and have taken the assignment one step further in providing predictions for aircraft and deck position, two key oscillations during flight operations. This report will describe the LSO environment, the approach we took to investigating pilot trending and key oscillations, and the development of a decision support interface to be implemented in the VISUAL system, a larger information system scheduled to be included on the LSO platform.

2.1 Day Operations

Daytime landing operations are referred to as Case I recoveries. With Case I recoveries, the aircraft fly by the starboard side of the ship (downwind) and perform a break once they are past the bow. The aircraft continues the turn to fly upwind at about 1 mile off the port side into a final, gradual 180 degree turn and arrives at a point 1/2 to 3/4 of a mile astern the ship. The landing area is then prepared for recovery, which is normally within a 45 to 60 second separation interval from the aircraft ahead. The Senior LSO or one of the two Airwing Staff LSOs "wave" the approaching aircraft from the LSO Platform.

(See Picture 1 attached at the end of the document).

Several other individuals assist these LSOs; some are LSO's and some are enlisted personnel. Normally the most senior LSO will be the "backup" or supervising LSO while a qualified, but more junior individual will be the "controlling" LSO. A third individual will copy shorthand comments into the LSO's Grade Log for use after the recovery in debriefing each pilot regarding his approach. Occasionally, other less experienced LSO's will observe the recovery for training. Information available to the LSO on the platform is provided in console displays including: Wind-over-the deck; Optical Landing System Status and lamp intensity indicators and controls; Clear Deck/Foul Deck (green light/red light) indicator; deck motion indicators; and a CRT display from a fixed centerline video camera view up the glidepath with stabilized crosshairs. This final source of information is the Pilot Landing Aid Television (PLAT) from which a videotape is recorded for later reference as well as mishap investigation. The LSO's communications resources consist of two radio sets (under his control), access to two radar controller radio circuits, a ship's telephone, several sound-powered phone circuits and one or two enlisted deck personnel in constant communication with other critical recovery operations workstation operators. The Captain and Air Boss can also communicate with the LSOs via their individual public address systems from the ship's tower.

The deck preparation includes stowing loose equipment, moving personnel from their launch to their recovery positions, moving aircraft from the landing area, and retracting the arresting cable. Simultaneously, the Optical Landing System is reset for the next type of aircraft approaching, and an enlistee on the LSO platform is also checking that the approaching aircraft is in the proper configuration for landing (landing gear locked down, tail-hook down and flaps/slats extended). As the aircraft approaches, the LSO assesses the pilot's response to deviations from on-speed, centerline, and glideslope. None of these factors remain constant as the landing area is angled and constantly moving to the right of the aircraft's flight path as the ship moves forward. The aerodynamics of the flight path is affected by the wind over the deck as it flows down off the stern then rises off the water 1/4 to 1/2 mile behind the ship at varying intensities. This effect is associated with a variance of aircraft airspeed as the pilot constantly corrects for these and his own induced deviations. At a point in the aircraft's approach, usually within 0.5 - 4 seconds of recovery, the LSO must then determine whether the aircraft position and speed is stable and safe enough to complete a landing to a touchdown area approximately 20 feet wide by 200 feet long, or signal the pilot to execute a wave-off. If the deck is still being prepared for the landing, the LSO must judge whether or not the deck can be cleared in time for a safe recovery. At the completion of a wave-off or landing the LSO will again begin assessing the next aircraft while verbally evaluating the last approach to his assistant.

2.2 Night Operations

Night operations fall into the Case II or Case III recovery classification. Case II recoveries follow the same approach pattern as Case I (daytime) operations, while Case III recoveries have the aircraft marshalling approximately 20 miles out and they come straight in to the carrier. Case III recoveries encompass situations where visibility is very low and/or weather conditions are poor. These are the most difficult recoveries. In all three types of recoveries, the approach patterns are identical from approximately ¾ of a mile from the ramp on in.

In Case III recoveries, the marshalling area is, as mentioned, 20 miles out. The aircraft then follow an instrument approach procedure to arrive at a point 10 miles behind the ship, then receive either verbal Precision Approach Radar guidance, a precise Instrument Landing System display in the cockpit, or are automatically controlled to touchdown by coupling the aircraft's auto pilot to the ship's Automatic Carrier Landing System. These approaches are generally more stable at the start due to the long straight-in flight path versus a turning approach to a short wings-level final as in Case I and II. The LSO is also presented with repeaters of the aircraft's performance via the information directly accessed from the precision radar. This is presented on a collector lens directly in front of the LSO in the form of a Heads Up Display (HUD). The LSO can use this information to anticipate errors from these visual and aural cues. The HUD is of greatest use when meteorological conditions restrict the LSOs normal ability to watch the aircraft approach visually. It is under these visually restricted conditions (darkness on the flight deck, darkness looking astern the ship, and the associated loss of depth perception at night, etc.), that the LSOs face their greatest challenges.

2.3 LSO Challenges

The Landing Signal Officer faces many challenges. Although LSOs primary concern remains safety, the ship is under significant pressure to maintain an extremely rapid recovery rate. The average recovery rates necessitate small intervals (45 to 60 seconds) between each landing, and there is constant pressure to not wave-off unless absolutely necessary. Additionally, due to EMCON constraints, the LSO minimizes use of the radio. Consequently, LSOs have little time to make the wave-off decision, are often forced to wait until the last possible second to make the final decision, and often may not have a good definition of what the last second is. Many of the issues an LSO must address are juggled between a series of trade-offs: safety vs. effectiveness; wave-off a bad pass vs. getting the pilot on board, etc.

During day operations in clear weather conditions, the approach radar is not normally used and therefore much of the information that would be available from this equipment (e.g., speed, actual rate-of descent, distance, etc.) is not directly available. During these approaches, the LSOs visually ascertain aircraft attitude, from which air speed can be inferred. As the LSO visually monitors the aircraft for proper glideslope and line-up, current throttle setting can also be inferred by listening to the engine. The LSO is also adept at predicting what the pilots next move might be based on the dynamics of the flight path. This is an important parameter because to reject the landing, the pilot must go to full-throttle, which may take up to 6.5 seconds to take effect, depending on the current throttle settings and aircraft type. This is a considerable period of time, given the split-second decision-making performed by the LSO.

In addition to recognizing particular aircraft and pilot model (different for each pilot and aircraft type), the LSO must also consider status of the deck condition and crew, specifically whether the deck is clear and crew is ready for recovery. If the deck is foul, the Air Boss will only notify the LSO if it is absolutely sure that the deck will not be ready in time and will call a no chance wave-off. Normally the LSO will wait until the last possible moment to wave the aircraft off, since the deck may be ready just at that last possible moment. Knowledge of the deck crew, their capabilities, and speed of preparation are used by the LSO to better estimate the likelihood that the deck will be clear. The pitch and roll of the deck must also be considered, as these factors influence the pilot's ability to perceive correct line-up and glideslope.

In addition to having little precise information, an ill-defined point of wave-off, working under extremely high time pressure and unpredictable environmental conditions, and having various pilot approach aspects to simultaneously consider, the LSO must estimate the wave-off window as it changes with the current conditions. The latest point of the wave-off window is defined as the point at which the LSO can wave the pilot off such that he will pass at a particular minimum height above the flight deck. Obviously this point shifts with the conditions and thus must be estimated by the LSO.

Finally, the LSO attempts to exercises as little control of the aircraft as possible, unless required by safety considerations. Otherwise, they can be more of a distraction to the pilot and potentially make matters worse. Being active Navy pilots themselves, LSOs have learned that having too much of an LSO in the cockpit can be very confusing. Along these lines, LSOs have also learned that it complicates things when they try to give pilots specific control instructions along more than one dimension at a time (e.g., passing on line-up and glide slope corrections simultaneously). They recognize that they have to prioritize the correction information they pass on, giving the pilot the most critical corrections first, followed later by additional less critical corrections.

The LSOs and pilots situation is greatly different at night. Night recoveries are considered much more dangerous than daylight operations. During night conditions LSOs use the approach radar, which gives them more accurate distance, azimuth, and bearing information such that deviations from glideslope and line-up can be readily calculated and displayed in the cockpit and repeated on the LSO Heads Up Display. Unfortunately, the accuracy of the LSOs information tends to exaggerate the trends that the LSO is monitoring when compared to daylight operations. Although more accurate deviation information is available to the LSO at night, he still relies heavily on visual perceptions of airspeed/attitude, centerline displacement, and glideslope control and is therefore challenged with integrating multiple information resources.

As a further complication, every pass and recovery of every pilot is graded. So, in addition to controlling the approach, the Controlling and Backup LSOs are also yelling out their observations for the Logging LSO to record for later use in the pilot debrief.

3 Approach

The goal of this project, in addition to developing display and platform recommendations, was to employ a combination of decision-centered techniques from the field of cognitive psychology and intelligent system techniques from the field of Artificial Intelligence (AI). Klein Associates brings expertise in cognitive psychology and decision-centered design, while the prime, SHAI, has AI expertise. The following sections will describe each method used in this project and they include: decision-centered design, CTA tools (Critical Decision Method and Knowledge Audit), case-based reasoning (CBR), Fuzzy Logic, Neural Networks, and Neural Networks Based Fuzzy Inference System.

Working with Landing Signal Officers to understand how they approach their tasks, and how best to support or enhance their performance has been a central theme of Klein Associates research for the past three years. For the Phase I work (Stottler & Thordsen, 1997), Klein Associates and SHAI were tasked to learn the overall task of recovering aircraft aboard U.S. aircraft carriers. It was a fairly broad approach that did not restrict itself to only the LSOs on the LSO platform, but also took into consideration the roles of enlisted personnel on the platform as well as those individuals in the tower and air operations (Air Ops). The goal of the Phase I research was to investigate the feasibility and usefulness of combining these cognitive and AI approaches. The Phase I resulted in display recommendations for the Controlling LSO (the individual who actually controls the aircraft through its final approach to the recovery).

For the Phase II, we concentrated specifically on pilot trending and oscillation considerations. Our objective in this Phase II effort was to identify the critical pilot trends and oscillations that an LSO must contend with, and to build an advanced decision-support interface that supports the split-second decisions and perceptual workload of the LSO. We identified three dynamic aspects of the approach oscillations: the aircraft, the deck, and the individual pilot (preferences, habits, and trends).

Our work is consistently guided by an approach to system design we have termed decision-centered. In the sections that follow, we will provide descriptions of decision-centered design and our approach to CTA knowledge elicitation and representation. Following that, we will introduce multiple AI techniques that were used to assimilate data collected from CTA knowledge elicitation. We turn then to a discussion of results of data collection as they relate to the problems and issues that surround development of a sturdy and flexible interface for the LSO operator.

3.1 Decision-Centered Design

A decision-centered approach (Kaempf & Miller, 1993; Klein, 1993; Klein, Kaempf, Wolf, Thordsen, Miller, 1997) to design involves using Cognitive Task Analysis (CTA) to identify the critical decisions, judgments, and cognitive elements of the task and then applying this information to any of a number of purposes. A decision-centered approach is best understood when presented in contrast to data-centered and system-centered approaches. The distinction is an important one for understanding consequences for design and operator performance, and is described below.

Many approaches to system design have been driven by the information-processing power of emerging new technologies. The capabilities of these high power systems permit access to vast amounts of raw data. Any or all of these data may be made available to, and sometimes even imposed on, the users/operators. The display and control design is data-centered and technology driven. This is not surprising given the great temptation, in the face of extraordinary memory capacity and operating power, to provide as much information to the individual as is technologically possible. The problem with a data-centered approach is that it does not take into account the shifting contexts in which many users function, it totally ignores what the user needs, when he or she needs it, or how it should be represented. We have seen many situations where individuals (e.g., pilots and other operators of complex systems) begin by turning off various support and warning systems because the operators say they are so distracting. Vast amounts of generic data can interfere, can result in information overload, and can force the operator to use valuable time sorting through data that may be important in other situations, in order to find the one or two pieces that are important in this situation. More is not always better. In fact, more is dangerous.

A second approach can be termed system-centered. The human factors community has recognized the difficulties of design that is technology driven. They understand that the information requirements of the user are of utmost importance if a complex system, which includes both the individual and the equipment, is to perform effectively. One approach to this has been system-centered designs, where data are organized and presented within the context of the various electronic or mechanical sub-systems. For example, on an aircraft these systems might include fuel, weapons status, hydraulics, and navigation. For the LSOs these might include the aircraft, the deck, the weather, etc. Overall, the system-centered approach has allowed marked improvements in interface design. It presents data organized in a way that helps the user understand the status of various systems and equipment. In the cockpit example, information for aircraft control, navigation, fuel management, ordnance management, and tactical and mission data are all available to the pilot in various forms and displays. However, the system-centered approach does not recognize that the data it provides generally plays a supporting role to the cognitive processes that the users require in order to achieve their missions. In other words, while the system provides a variety of data elements, it is left to the user to synthesize the data to answer a particular question, or to fit data to the needs of the current situation. For example, a system display that shows a pilot the status of the fuel system is very helpful, however, this information is usually only a sub-part of the overall information the pilot may need. More often than not, fuel status is related to other factors such as distance and time, and in the aviation domain, wind and speed emerge as important factors as well. The integration of these factors would be more useful, perhaps, than just a fuel status display.

It is our view that for the user to think and act effectively, that data presentation has to take into account the context of the individuals decision making, rather than being data- or system-centered. In effect, it needs to be decision-centered. To achieve this, the information must be presented in a functionally meaningful way the information must be framed by the nature of the critical decisions and judgments (i.e., decision requirements) within a particular context or situation, and made available to system users in ways that support thinking and action.

A decision-centered approach, as the name implies, anchors the design around the decisions that will confront the user who is involved with the systems tasks. A decision-centered approach can be viewed as a variation of Cognitive Systems Engineering, one in which decision requirements (the most critical and difficult decisions and judgments) provide the foundation for the generation of the design principles and recommendations. Decision-centered design is beneficial in any domain that involves interaction of human and smart machines to accomplish complex tasks. However, in domains that involve extreme time pressure and risk, as in the LSO domain, decision-centered design is critically important to optimal performance and avoidance of mistakes.

3.2 Cognitive Task Analysis

Our approach to decision-centered design is grounded in the use of Cognitive Task Analysis (CTA) tools and techniques that are associated with critical event and critical decision methodologies. The key element of these approaches is that they derive their data from a combination of observations of and interviews about real-world decisions and events. For this project, the CTA helped us identify and document cognitive elements (i.e., critical decisions and judgments) of the LSO task, so that we could incorporate these critical elements into the design of a flexible and high-powered interface.

CTA as conducted by Klein Associates researchers is an in-depth examination of an individuals expertise in the context of his or her job the cues and patterns of cues, strategies, challenges, discriminations, assessments, expectancies, goals, and ability to detect and anticipate problems. These methods are in contrast to other more generic or abstract CTA methods derived from a task analysis approach. Rather than decompose the task into subcomponents, the intent of our CTA methods is to get inside the head of the expert and understand the rich cognitive elements that are difficult to articulate For The CTA tools we used to uncover these issues include the Critical Decision Method (CDM) and the Knowledge Audit, and are described below.

3.2.1 Critical Decision Method

Klein Associates most frequently used research tool, the Critical Decision Method (CDM), has been used in dozens of studies of decision making and problem solving. CDM interviews are based on Flanagan's (1954) critical incident technique and are organized around an initial, unstructured account of a specific incident. The incident account is generated by the interviewee in response to a specific open-ended question posed by the interviewers, and it provides the structure for the interview that follows. By requesting accounts of a certain type of event, and structuring the interview around that account, potential interviewer biases are minimized. Once the report of the incident has been completed, the CDM interviewer leads the participant back over his or her incident account several times, using probes designed to focus attention on particular aspects of the incident and solicit information about them. Solicited information depends on the purpose of the study, but might include presence or absence of salient cues and the nature of those cues, assessment of the situation and the basis of that assessment, expectations about how the situation might evolve, goals considered, challenges faced, and options evaluated and chosen. And because information is elicited specific to a particular decision and incident, the context in which the decision maker is operating in remains intact and becomes part of the data record.

CDM has been highly successful in eliciting perceptual cues and details of judgment and decision strategies that are generally not captured with traditional reporting methods, and has been demonstrated to yield information richer in variety, specificity, and quantity than is typically available in experts' unstructured verbal reports (Crandall, 1989). The information obtained via these methods is concrete and specific, reflects the point of view of the decision maker, and is grounded in experience. Detailed descriptions of CDM and other work surrounding it can be found in Klein et al. (1989) and Hoffman et al. (1998).

3.2.2 Knowledge Audit

Another CTA tool is the Knowledge Audit, developed under a contract with the Navy Personnel Research and Development Center (Militello et al., 1997). The objective was to develop a streamlined set of CTA tools, which could be used effectively by people outside of the cognitive research community. The Knowledge Audit focuses on the categories of knowledge and skills that distinguish experts from others. These categories include metacognition, mental models, perceptual cues and patterns, analogues, and declarative knowledge. The Knowledge Audit provides an efficient method for surveying the various aspects of expertise. The method does not attempt to find whether each component of expertise is present for a given task. Rather, it employs a set of specific probes designed to describe the type of knowledge or skill and to elicit examples of each based on actual experiences. The primary strength of the Knowledge Audit is that it enables us to survey rapidly the nature and breadth of skills involved in expertise in a given domain.

The next section will describe the Artificial Intelligence (AI) methods that were used, in conjunction with data derived from the CTA methods, to build an advanced decision-support tool for the Landing Signal Officer workstation. CTA data was a critical ingredient in building an intelligent system, and a more detailed account of how the CTA data fit into AI models of design is described in later sections. Next is a description of AI methods utilized in this project.

3.3 Case-Based Reasoning

Case-Based Reasoning (CBR) reasoning is a knowledge representation and control methodology based upon previous experiences and patterns of previous experiences. These previous experiences (previous carrier landings), or "cases" of domain-specific knowledge and action, are used in comparison with new situations or problems. These past methods of solution provide expertise for use in new situations or problems.

Much of the research in Case-Based Reasoning is directed toward retrieving similar cases and determining useful definitions of similarity. It was found to be useful in retrieving similar or relevant past approaches. For a pilot trending system, the cases are simply previous examples of carrier landings, including all information available from the ship's systems, from which inferences and comparisons can be made using CBR.

Because CBR is based on the ways humans think, it is a very natural way to support the human decision-making process. For example, the LSOs all described how important it was to have seen several previous approaches made by the incoming pilot. The CBR system aids this process by retrieving similar approaches, in case this particular LSO does not have much experience with this particular pilot, for these conditions.

By retrieving a set of very similar, very relevant cases, the CBR system helps the LSO make qualitative assessments of the current approach based on the particular pilot's tendencies and trends. This assessment is based on the statistics of the retrieved similar cases, weighted based on their degree of similarity to the current situation.

3.4 Fuzzy Logic

Zadeh introduced the concept of fuzzy logic in 1965. Since then, fuzzy logic has advanced in a wide variety of disciplines such as control theory, topology, linguistics, optimization, and category theory. Unlike a crisp set, a fuzzy set allows partial membership. Fuzzy logic is a generalization of the traditional TRUE/FALSE bi-level logic, one that allows for non-sharp transition, representing a region of partial truth, between absolute true and absolute false. For example, although the assertion that an individual is male is either true or false (and is therefore crisp), the assertion that an individual is lean is not so clear-cut. **Figure 1** demonstrates how the fuzzy sets may be used to capture this concept. A person with a body fat percentage of 16.5 has membership values of 0.12 and 0.43 in the "lean" and "moderately overweight" fuzzy sets, respectively.

The basic architecture of a fuzzy logic data analysis system is illustrated in **Figure 2**. The numerical input data is codified through the fuzzifier into the equivalent linguistic parameters (such as lean, moderately overweight, and obese), with associated membership function values. The inference engine uses the knowledge in a particular representation to derive some expert conclusion or offer expert advice. It includes the system's general problem-solving knowledge. Various rules in the knowledge base and decision-making logic are invoked and recover the decision actions with different degrees of emphasis depending on their respective membership values.

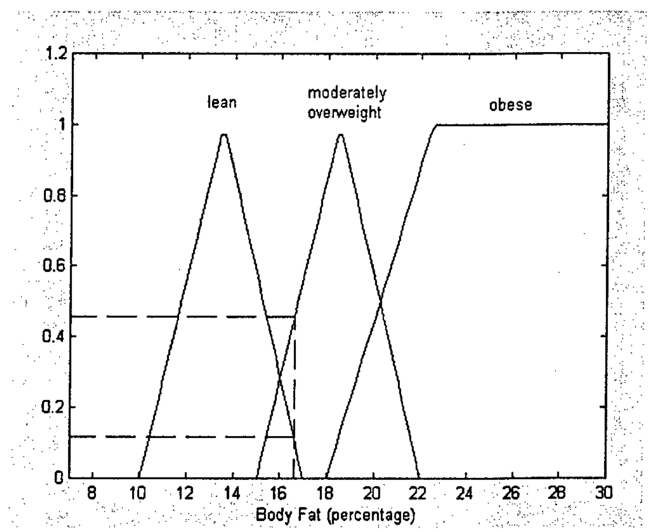


Figure 1. Fuzzy Membership Functions

The final stage in the fuzzy logic data processor aggregates all the inferred fuzzy data and produces an appropriate conclusion or classification of the system's input. If the system's output needs to be in non-fuzzy numerical format, it is the responsibility of the defuzzification module to convert fuzzy data to numerical from.

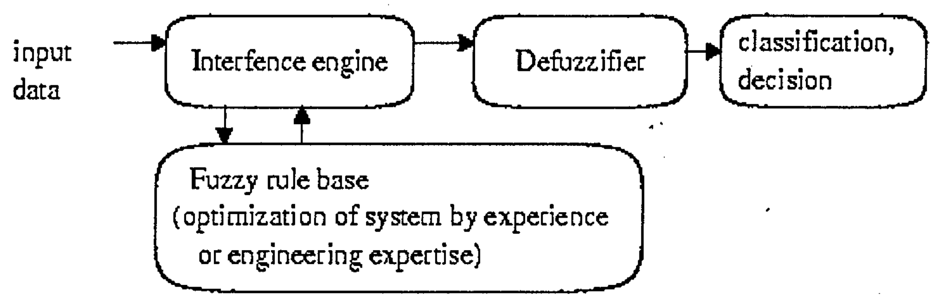


Figure 2. General architecture of fuzzy logic data analysis system

Fuzzy logic was found to be useful in conjunction with case-based reasoning to determine similar landings. In addition, fuzzy logic was found beneficial, when combined in a neural network type system, in the prediction of future aircraft locations.

3.5 Neural Networks

Neural networks are an approach to machine learning which developed out of attempts to model the processing that occurs within the neurons of the brain. By using simple processing units (neurons), organized in a layered and highly parallel architecture, it is possible to perform arbitrarily complex calculations. Learning is achieved through repeated minor modifications to selected neurons, which results in a very powerful classification system. Neural network software is used to recognize, and also to run at desired conditions. Applications include handwriting recognition, fingerprint identification, control of chemical processes, speech recognition, credit analysis, scientific analysis of data, and in neurophysiological research. Neural networks are also referred to as neural nets, connectionism, and parallel associative memory.

Neural networks techniques were utilized in conjunction with fuzzy logic techniques to create a neural network based fuzzy inference system for learning predictions for future aircraft/pilot locations.

3.6 Neural Network Based Fuzzy Inference System

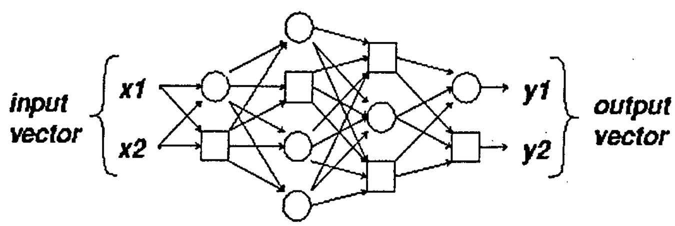


Figure 3. An Adaptive Network

A neural network based fuzzy inference system (**Figure 4**) is a multi-layer network in which each node performs a particular function (e.g., a fuzzy function) on incoming signals (as well as a set of parameters pertaining to the node). The nature of the node function may vary from node to node, and the choice of each node function depends on the overall input-output function which the neural network is required to carry out. A neural network has two types of nodes: an adaptive node (represented by a square in **Figure 4**) has parameters that may be updated by a learning algorithm, while a fixed node (represented by a circle) has none. A neural network-based fuzzy inference system is comprised of several layers of nodes, as illustrated in **Figure 4**. The node function of each node in the **premise** layer of nodes is a fuzzy membership function, which specifies the degree to which the node's input parameter satisfies some linguistic quantifier associated with the node. The $\prod$ layer of nodes outputs the firing strength of the fuzzy rules, and the **N** layer normalizes the firing strengths. The consequent layer performs (Sugeno-type) defuzzification, aggregated by a single weighed sum node in the **final** layer. Fuzzy IF-THEN rules that the system's structure is based on may be obtained from human experts or constructed automatically based on the format of training data. The learning rule is a hybrid of gradient descent and least square estimation of parameters. In the forward pass of the learning algorithm, signals go forward till layer 4 and the consequent parameters are identified by the least squares estimate. In the backward pass, the error rates propagate backward and the premise parameters are updated by gradient descent.

The neural network based fuzzy inference system was trained using various landing passes and learned to predict future aircraft/pilot locations.

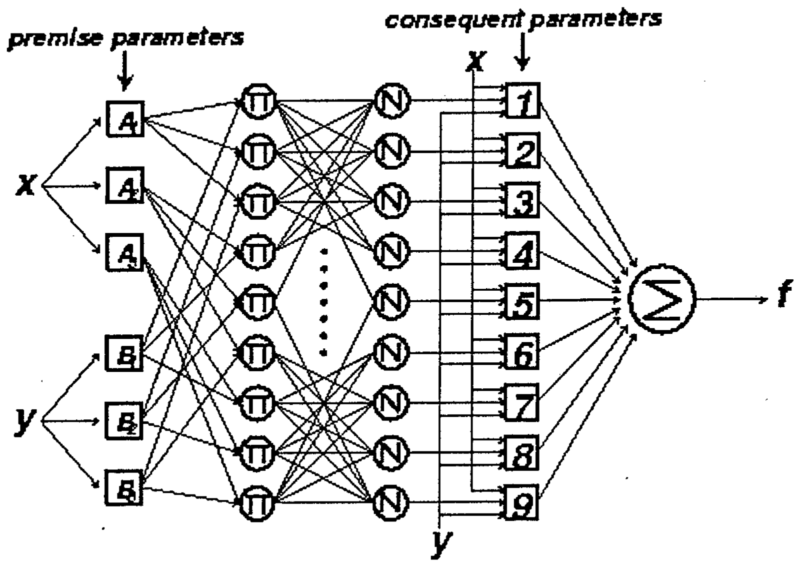


Figure 4. Neural Network based Fuzzy Inference System

4 Phase II Objectives and Accomplishments

4.1 Objectives

The primary objective was to buttress LSO decision making by developing pilot trending and ship oscillation recognition decision aids. In support of this primary objective are several subsidiary ones:

- Elicit Important Pilot Trending and Decision Support Considerations
- Elicit Important Approach Parameters and Similarity Measures
- Elicit Important Pilot Considerations and Similarity Measures
- Develop Pilot Trending and Ship Oscillation Recognition Techniques/Software
- Design/Implement LSO Interface for Pilot Trending and Ship Oscillation
- Test Prototypes

4.2 Data Collection

During the early stages of this Phase II project we continued Cognitive Task Analysis (CTA) of the landing signal officers (LSOs) and began developing an LSO interface. The envisioned interface design was designed to provide the LSOs with critical information in appropriate formats to better support their understanding of how the pilots trends and the oscillations of the aircraft and ship are influencing the current recovery for a particular pilot under particular circumstances (i.e., help them land the planes more safely and expediently a somewhat contradictory LSO mandate). Our approach was based on decision-centered design concepts wherein the critical decisions and judgments required of the LSOs drove the design development.

4.2.1 Knowledge Elicitation

Our primary subject matter experts for the CTA were U.S Navy Commander, Frank Pfeiffer (ret.), a former CAG LSO, and the instructors at the LSO Training Center at NAS Oceana, Virginia Beach, VA. CDR Pfeiffer served as a U.S. Naval Pilot and LSO for many years and is currently employed as a pilot for a major commercial airline. During the Phase I and Phase II, we interviewed CDR Pfeiffer on multiple occasions totaling around 100 hours. Many of the sessions were one to two days in length. In addition to sessions with CDR Pfeiffer, we have visited the LSO School on about 12 different occasions where we performed knowledge elicitation on both the instructors and students, and had them react and comment on design concepts and previous data analyses we had conducted. In the early stages of the project, the LSO School personnel were additional sources of data and in the latter stages, they served primarily for evaluation (providing feedback about the display) and testing of the interface designs, which will be described later in the document.

We employed the Critical Decision Method (CDM) and Knowledge Audit to elicit critical pilot trending and aircraft and ship oscillation data, and used more informal interviewing methods to elicit background information about the overall LSO task environment. For pilot trending we elicited both the knowledge relating to an approach that is important for the LSO to know, and how to identify similar approaches. Foremost, we elicited important approach parameters and similarity measures (i.e., what information about the approach is most important to the LSO, and how is similarity between approaches defined) This knowledge was needed to determine what should be displayed to the LSO and when it should be retrieved. We also elicited important pilot considerations and similarity measures (i.e., what knowledge about a pilot is most important to the LSO, and how is similarity between pilots defined, for purposes of aiding the LSO).

To truly employ decision-centered design, we needed to begin by understanding how LSOs with experience and expertise break down their job from a cognitive perspective. The results of the Phase I CTA revealed that there were several key types of information that were critical to the judgment/decision required of the LSOs to perform their job successfully, and we used these as a springboard for further elicitation in the Phase II. These include:

Deviations of the aircraft glide path from the glideslope, dictated by the basic angle of the day.
Deviations of the aircraft speed from the ideal, based on its attitude and the particular aircraft type.
Deviations of the aircraft line up from the centerline of the landing area on the angled deck.
Abnormal aircraft configuration, based on the aircraft type.

It is important for us to stress that the above list identifies critical information requirements of LSOs, but these should not be confused with decision/judgment requirements. The decisions and judgments will provide us contexts within which these data are appropriate and will provide frames for design concepts. This will be addressed more, later in the report.

For each of the above points (glide path, attitude, line up, and configuration) the CTA in the Phase II also brought out the important conditions under which the landings were occurring (Case I, II, or III). Case I (day) and II (night) refer to good weather, visibility, and/or sea conditions. Case III refers to poor weather, visibility, and/or sea conditions.

In addition, two other criteria were identified as important influences on the decision making of the LSO: the type/model of aircraft and the experience/competence of the pilot. The type/model of aircraft dictates the characteristics and responsiveness of the aircraft. This in turn influences how much the LSO can let it drift off centerline (the larger the wingspan, the less drift that can be allowed), how quickly the engine can spool up (the slower the spool up time, the further out the power call must occur), etc.

Our knowledge elicitation in Phase II uncovered that the LSOs have five categories they use to classify the experience/competence of the pilots: New Guys (FNG), Average Pilots, Top Pilots, Problem Children (those pilots who were having a lot of difficulties), and Staff/COD pilots (those pilots who did not get to land that often on the carrier). During one of the data review sessions, the LSOs said that they treat Problem Children and Staff/COD pilots the same as FNGs, so we collapsed these three into the FNG category, leaving 3 categories: FNG, Average, and Top Pilots.

Furthermore, the Phase I data collection uncovered that the LSOs consistently visualize the overall recovery of aircraft by segments that are related to where the aircraft is in its approach pattern. In the Phase II, the LSOs helped us determine that the critical segments for the pilot trending and oscillation recognition components are primarily from when the aircraft is roughly one mile out all the way on in to the deck. While 1 mile in is the critical area, we collected data for the entire Case I & II approach from where the aircraft first makes the pass along the starboard side of the ship. This would be the equivalent of greater than three miles out for a Case III recovery. The LSO terms for these segments are:

The Pass
The Break
The 180 (Case I & II approaches) or 3 NM (Nautical Miles) out (Case III).
The 135 (Case I & II approaches) or 2 NM out (Case III).
The 90 (Case I & II approaches) or 1 NM (Case III).
The Start (X). Approximately - NM from the ramp.
In the Middle (IM). Approximately NM from the ramp.
In Close (IC). Approximately 1/8 NM from the ramp.
At the Ramp (AR). Right at the ramp (stern of the ship)
In/Over the Wires (IW or OW): The area where the arresting wires cross the landing area. IW implies the aircraft has been trapped while OW implies it missed the wires.

Note that from the Start (X) on in, the three Cases are identical with the exception of the lighting (day/night) and weather conditions (clear, heavy rain, stormy, etc.).

Knowledge elicitation only represents one aspect of the CTA methodology. Further analysis and data representation are necessary in order to make sense of the information before the data is shared, in this case, with the Artificial Intelligence experts, and subsequently fed into AI models for development of a decision support tool. The next section describes how the data was organized into a useful form that could be used by AI technicians.

4.2.2 CTA Representation

Representation of the data collected from the interviews is a crucial aspect of the CTA methodology. A Decision Requirements Table (DRT) was created to organize the information that was elicited in the CTA interviews (see appx. T grid notes and corollary). DRTs are a popular format for organizing data, especially in terms of decision requirements and/or the information needed to make the critical decisions. For example, we collected data about how an aircraft can deviate from the glide slope (from dimension 3), under Case II conditions (dimension 2) within flight segment IM (dimension 1).

We refer to the tabulation of information across dimensions as a decision requirements table. Figure ? shows a sample Decision Requirements Table that is not completed. A completed decision requirements table for the LSO is found in Appendix T. The decision requirement tables and cognitive task analyses from the Phase I and Phase II identify the critical decisions and judgments around which all design recommendations are focused (i.e., decision-centered design).

The following probes organize the DRT table illustrated below:
How can they deviate (e.g., go high, low, left, right, etc.)?
What are the indicators of these deviations (angle of bank, altitude, etc.)?
What are the specific cues/indicators to the LSO (how much right wing tip is visible, etc.)?
At which point can the LSOs discriminate the deviation (e.g., 30 ft. off glide slope)?
At what value or point does a deviation become a problem (e.g., 5 ft. low)?
Are there differences (when it becomes a problem) for the three different pilot types?
And finally, why are these data important for the LSO? That is, what are they trying to do that requires them to need this information?

CaseHow Can Deviate
Indicators
Specific Cues/Indicators
Discrimination Ability
When does Deviation Become a problem? Differences for Pilots/Pilot Types?
Glide Slope/Glide Path
1200 ft. decent beginsAttitude/
SpeedLine UpConfiguration of aircraftFigure ?: Decision requirement table example

	Case	**How Can Deviate**	**Indicators**	**Specific Cues and Indicators**	**Discrimination Ability**	**When does Deviation "Become a problem?"**	**Differences for Pilots/Pilot Types?**
Glide Slope/Glide Path 1200 ft. decent begins							
Attitude/ Speed							

Line Up							
Configuration of aircraft							

Table 1: Decision requirement table example.

4.2.3 Data Sources

In parallel to the CTA work, we examined several other data sets. These data sources also fed into the AI models. These are briefly described below:

SPN-46 Radar Data. The SPN-46 radar tracks several aspects of each approaching aircraft and of the ship at a rate of approximately 15-20 samplings per second. For each aircraft it collects plane position information using three coordinates: distance from the ship, horizontal position with respect to the ship (line up), and altitude. In addition, it processes some of these data to also provide the aircraft's closing speed and its sink speed. The SPN-46 radar also tracks the ships pitch and roll in degrees. Header data includes the time-hack, pass number, the radio channel in use, and aircraft side number.

LSO Comments/Grades. Every pass is graded by the controlling/backup (senior) LSO. These grades, or comments, describe the aircraft's location and characteristics for each segment of the approach, at least from the start (X) in to the wires. An annotated example of a LSOs grade/comment on a pass is provided in Figure 2. A glossary of the LSOs grading is included in Appendix U Figure 2.

Automated Performance and Readiness Training System (APARTS) Program, Data, & Reports. APARTS is a program used by the LSOs to input records of every recovery pass. It works from a MS ACCESS database and can generate a variety of reports, both for the individual pilot and the squadrons. A key piece of data that APARTS uses is the LSOs Grade/Comments for each pass. It is from these inputted APARTS data that our system will extract the information about a pilots trends and history. (Appendix E).

Accident Summary Reports. The U.S. Navy Safety Center, located at the Norfolk Ship Yards, Norfolk, VA keeps a complete set of summaries of all incidents that occur in the U.S. Navy. We requested a set of recovery incidents involving fixed wing aircraft, where the LSO was mentioned. Several hundred incidents were retrieved. We studied these for any possible patterns and information that might prove to be useful in this project. An example of a report is presented below. Note that the summary report is informative, but also rather cryptic. They did, however, give us a feel for the range of incidents that occurs on the carriers, beyond the typical ramp strikes we had learned about through other data sources.

Example of Naval Safety Center Accident Summary Report

ACFTMOD EVENT_SERL	F014A 15753

-------------EVENTSUMMARY------------

During night CV bolter, ACFT drifted right & stbd wing tip impacted 2 ACFT spotted on stbd side of foul line. ACFT subsequently recovered safely. Mishap cause factors: aircrew error improper landing technique. Pilot failed to correct for right drift at the ramp. Line up corrections throughout the approach were timely & appropriate. Just after crossing the ramp ACFT established a right drift. At that point ACFT was waved off for being too high to land safely. The pilot transitioned to inside the cockpit to set the attitude & monitor his instruments. Mp stated he sensed the right drift but did not believe it to be excessive & initiated no correction prior to touchdown. Controlling personnel factors backup LSO failed to make a timely line up call when right drift was noted as ACFT crossed the ramp. The backup LSO is responsible for monitoring ACFT line up during the approach. He must monitor line up all the way to touchdown & be ready to give a mandatory UHF call when a deviation occurs, even if the ACFT is over the wires. The backup LSO did see the right drift at the ramp but elected not to issue a line up call fearing ACFT would touchdown on left main mount only. It is the backup LSO's responsibility to call for the correction, & trust the pilot to be aware of his proximity to the deck & make the correction appropriate to the situation.

Video Tapes of Recovery Incidents/Accidents. The instructors at the U.S. Navy LSO School at NAS Oceana, Virginia Beach, VA provided us with a video compendium of carrier recovery incidents. These were extremely informative, and sobering. The video provided us with a sense of the acute time pressure the LSOs work within and the dangerous nature of the aircraft recovery process.

4.3 Pilot Trending Analysis

To perform the pilot trending research it was required that we get, from the Navy, data associated with a large number of carrier landings, for the full-range of aircraft that the LSO must help land. We tapped specific data sources for this task, which included SPN-46 data (range, bearing, and altitude data over time for the incoming aircraft), and ship motion data (pitch, roll, heave, and, preferably, velocity) retrieved from at-sea landings. The most critical data source used for the pilot trending, however, was the LSO comments and grades, which already existed in an APARTS data base for each pilot (Appendix E).

4.3.1 Case-Based Reasoning (CBR)

We applied the technique of Case-Based Reasoning (CBR) to address the Pilot Trending problem. Much of the research in Case-Based Reasoning is directed toward retrieving similar cases and determining useful definitions of similarity. For a pilot trending system, the cases are simply previous examples of carrier landings, including all information available from the ship's systems, from which inferences and comparisons can be made using CBR. In order to define what constitutes similarity between approaches and between pilots from the LSO perspective, the LSO's notation and comments provided one aspect to this representation. These comments captured an approach's motion pattern at a high-level of abstraction. These high level comments then were used as a basis for assessing the similarity between two approaches.

From another perspective, case representations often include features at a low level, and features at a high level of abstraction. For approaches, the low level features included the approach data (range, bearing, altitude), and the high-level features included the LSO's comments. Obviously, since many of the LSO's comments capture the approach at a high-level of abstraction, there was some redundancy of information.

CBR uses cases to record the experience know-how and process the reasoning for retrieving solutions from such subsequently. A case is a contextualized piece of knowledge representing an experience. It contains a past lesson that is the content of the case and the context in which the lesson can be used. In our project a case consists of the LSO comments of the flight performance at different stages as the specific aircraft approaches the aircraft carrier under the same pilot and the same environmental conditions.

The CBR software delivers two major objectives and show its results on the display:

- Approaches based on similar conditions: Retrieval of the number of approaches with similar conditions and the total number of traps per pilot with this aircraft type.
- Trend Patterns: Retrieval of similar landing trend patterns from stored cases; display them graphically; and show the LSO comments of the closest case.

The case-based reasoning (CBR) for pilot trending consists of

1) Indexing,
2) Similarity definition, and
3) Retrieval algorithm.

We use CBR to represent the pilot trending knowledge and use that knowledge for LSOs to evaluate the landing performance; and to provide related trending flight cases. Through CBR, we represent prior approaches and the affiliated LSO comments as cases. Retrieval of similar cases is then performed to provide the similar cases for pilot trending analysis. Upon reading the pilot information, the current weather condition, and the aircraft position (SPN-46), the pilot trending system uses the case base reasoning system to retrieve the most similar patterns from previous cases stored in the APARTS historic database. The recent similar 10 patterns, and the current one are displayed on the displayed panel in graphical format. The associated LSO comments may also be displayed.

The overall pilot trending architecture is as depicted in Figure 5. The *Pilot Trending Analysis* box in the figure is handled via case-based reasoning.

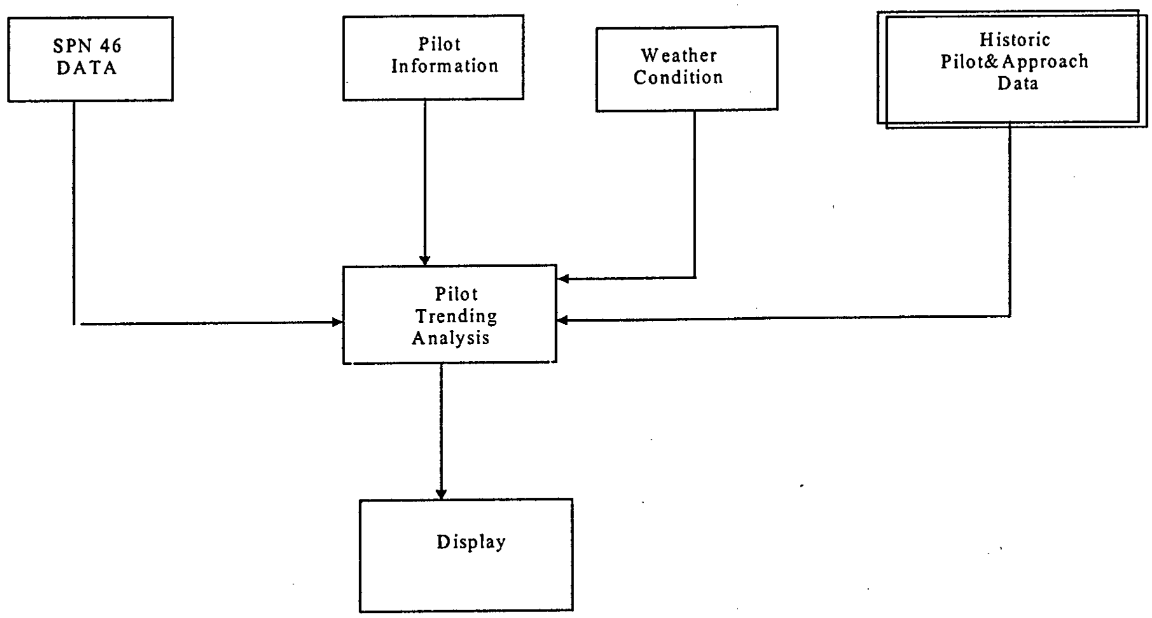


Figure 5. The Architecture Of Pilot Trending System

4.3.1.1 Indexing

Several features are selected in defining the indexes for the cases. Indexing facilitates retrieval of similar cases. The multiple features selected as indexes are pilot name, aircraft type, glideslope, lineup, and day/night.

4.3.1.2 Similarity Definition

Similarity assessment is the process of comparing an incoming flight pattern to stored approach cases using the similarity definition and indexes to produce a similarity score. This is done progressively as the aircraft approaches the aircraft carrier. As more flight pattern data is available from stages of at the start(X), in the middle(IM), in close (IC), to that of at the ramp(AR), the similarity assessment is performed for each of the fours stages.

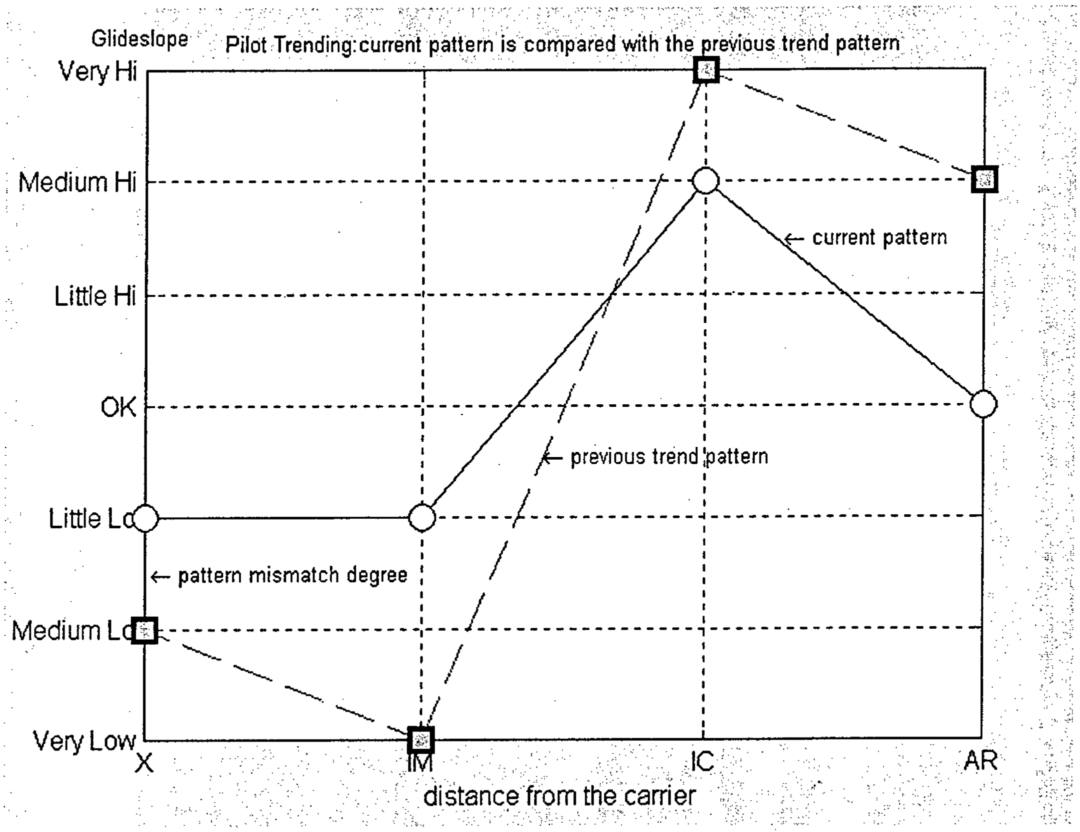


Figure 6. Similarity assessment with glideslope matching

As shown in Figure 6 the pattern matching degree is evaluated by comparing the current glideslope pattern with that of the stored ones. A similar procedure is applied to lineup before the system decides what stored case to be retrieved as the closest one.

The above similarity definition takes the following into consideration.

i) If the glideslope difference between the current one and that of the stored one is small, it will have a relatively small *matching index* value and is therefore considered close.

ii) At each stage the *matching index* takes a weighted sum on the mismatch of the current stage and that of the accumulate mismatch of the previous stages.

The matching index is a direct measure on how close the stored case is to the incoming flight. With the proper normalization of the linguistic to numeric conversion, e.g.,

- Very High = 0.5
- Medium High = 0.33
- Little High = 0.17
- OK = 0
- Little Low = -0.17
- Medium Low = -0.33
- Very Low = -0.5.

Flight Path Deviations to Linguistic Conversion

For flight data that does not have associated linguistic data, PADAL has to determine the appropriate linguistic conversion from numerical flight path data. Fuzzy logic is employed in PADAL to perform flight path to linguistic conversion. Fuzzy lineup and glideslope functions are represented in Figure 7. The lineup category consists of 7 fuzzy sets, ranging from significant left lineup (_LUL_) to significant right lineup (_LUR_). The glideslope category is subdivided into 7 analogous fuzzy sets which construct a "very high" (_H_) to "very low" (_LO_) classification of the aircraft's glideslope. These fuzzy sets map directly onto the comments used by LSOs to describe the aircraft's position.

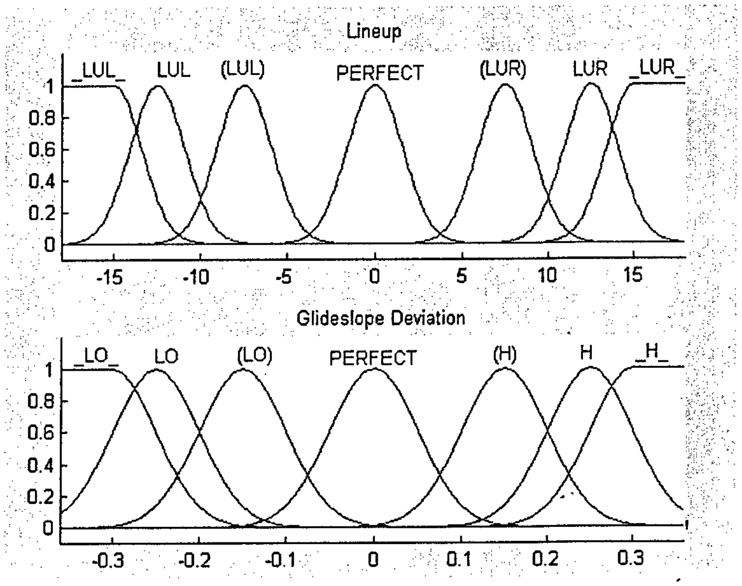


Figure 7. Lineup & Glideslope Fuzzy Membership Functions

Similar fuzzy definitions are constructed for various other parameters that define the landing trajectory. These fuzzy concepts enable the system to classify any point in the landing trajectory by associating fuzzy membership values with it.

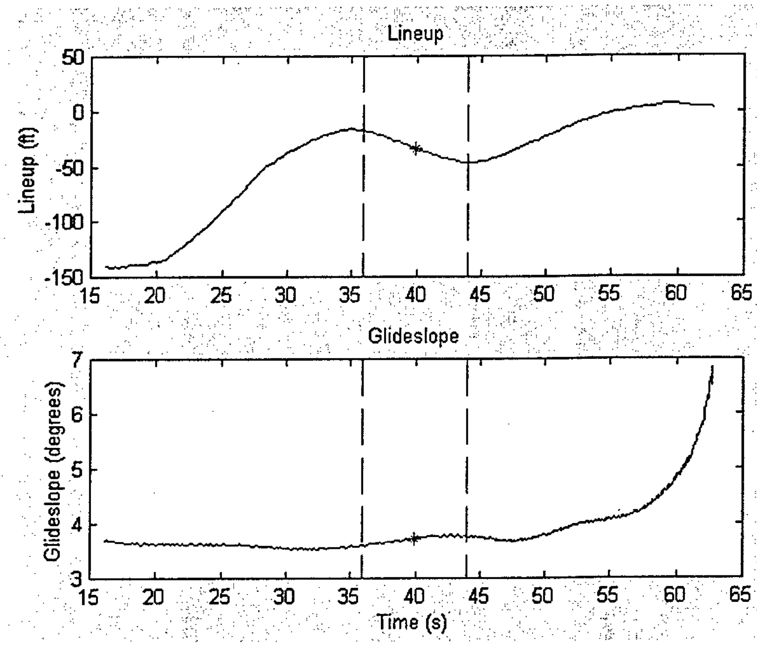


Figure 8. Lineup and Glideslope vs. Time

For example, a marked point in Figure 8 has the glideslope deviation from the nominal glideslope (3.5°) of 3.7314°-3.5° = 0.2314°, which corresponds to the following glideslope classification:

Glideslope:

$\mu_{\_LO\_}$	= 0.00	$\mu_{\_H\_}$	= 0.39
μ_{LO}	= 0.00	μ_{H}	= 0.93
$\mu_{(LO)}$	= 0.00	$\mu_{(H)}$	= 0.27
$\mu_{PERFECT}$	= 0.00		

This means that an aircraft in that position is very likely to be classified as high by a landing signal officer, somewhat likely to be classified as very high or a little high, and extremely unlikely to be classified as low.

4.3.1.3 Retrieval Algorithm

After the case-based reasoner has determined the most similar landings, the retrieval algorithm retrieves these similar landings from stored cases; displays them graphically; and displays the LSO comments of the closest case. Based on the information of the incoming flight, the CBR system performs and provides the following for display on the display panel.

- <u>Total traps</u> are the number of cases that have the pilot name index matching that of the incoming pilot.
- <u>Similar conditions</u> are the number of cases that have the index (pilot name, aircraft type, squadron, and day/night) matching that of the incoming flight.

In addition, the ten most recent and similar stored cases that match the current flight pattern will be displayed in four panes, corresponding to X, IM, IC, and AR stages respectively, with the following features.

i) A graphical representation of the past ten similar flights' trend will be displayed
ii) Four graphical windows will be aligned with the LSO comment summary for each of the four stages, i.e., X, IM, IC, and AR.
iii) Each window contains 10 most recent similar approach data.
iv) In each window, there will be a Cartesian coordinate with the horizontal axis showing the lineup and the vertical axis representing the glideslope.
v) The trend data will be represented as dots of varying sizes(recency). Red circles may be used for the most similar ones.

4.4 Prediction of Plane Trajectory & Ship Motion

To guide an aircraft to land more safely and smoothly aboard aircraft carriers, Landing Signal Officers (LSO) on board need to advise incoming pilots to adjust their flight patterns continuously. The ability to predict how the aircraft motion trajectory may look can facilitate LSOs in making their guiding decision. Typically, the flight pattern is carefully observed and guided when aircraft is within one nautical mile (1 NM) from the landing deck in open sea. This corresponds to slightly more than one minute in real flight time. A radar system records all the trajectories of different pilots flying various jet fighters. This data may be used to train a system for subsequent prediction purpose. A projection of 2 seconds profile ahead of the current flight position is usually considered appropriate. Another useful subject that helps LSOs in this guiding process is the prediction of the ship's deck motion in the forthcoming 4 seconds. If the deck is predicted to tilt up, an LSO can advice the pilot to land somewhat higher as it touches the deck. Misleading prediction may lead to crash or waveoff. A reliable prediction algorithm is therefore essential for this task.

This task consisted of solving a time series prediction problem in which past and present motion profiles are provided to the prediction system to predict the motion in the next few seconds. No other information was provided to base the prediction on, such as present engine setting or wind speed and direction. Thus the general problem was to take as input noisy time-series profiles with a maximum duration of about 1 minute and provide a 2 second hence prediction of the plane's location. This problem may be depicted as in Figure 9.

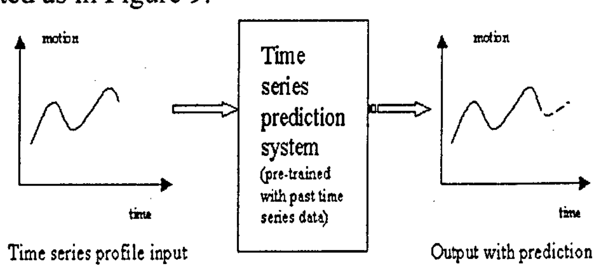


Figure 9. Time Series Prediction

Potential candidates for solution of this problem included statistical, Fourier, wavelet, neural networks, fuzzy logic and other transform and machine learning techniques.

The data set in the aircraft-landing domain consists of numeric aircraft trajectory curves recorded by a radar positioned aboard a ship. The radar monitors landing aircraft's lineup (its horizontal distance from the center of the deck) and glideslope (its approach angle). All the landing trajectory curves considered in the course of present study is subdivided into five categories based on the landing aircraft type: F-14A, F-14B, F-18, A-6, and C-2. These categories provide a natural way of subdividing the original trajectories into modules. In addition to the radar-recorded data, new automatically generated curves (grouped into modules) were added to the system in order to determine how the size of the data set affects the performance of the modular design. These curves were produced by a linear convolution of the original curves within each aircraft category.

Typically, the input motion profiles can be clustered into several loosely coupled categories. This can be the basis of modular decomposition. The landing motion profiles of F14A, F14B, F18, A6, and C-2, for example, are different though they share some common characteristics. Figure 9 depicts the input space of five such interconnected clusters.

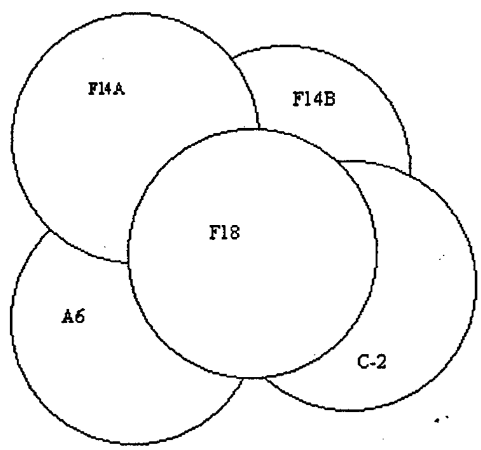


Figure 10. Clustered Data in Input Space

This modular nature of the input data space was used to modularize the design in the learning stage by training different neural network based fuzzy inference systems with respect to each input data category. One can take further advantage of the parallel processing technique to reduce the computation time. Aggregation of these individually trained modules produced one generalized module for prediction purpose. This generalized module is expected to have prediction performance comparable to that of the system trained with the traditional non-modular approach. The computation effort and the design complexity are both expected to be drastically lower with the proposed modular approach.

The neural network based fuzzy inference system's ability to construct an input-output mapping in a fast and efficient manner was one of the many factors that led to its selection for the aircraft prediction problem. The system was trained with a subset of the past data before it was engaged in the on-line prediction task. After training the system with a subset of the past profiles, the system was exposed to unforeseen approaches and forecast its profile in the next few seconds on-line.

Figure 11 shows a sample aircraft lineup trajectory (filtered position), the trajectory predicted by the neural network based fuzzy inference system (ANFIS), and the trajectory predicted by a 1st order polynomial extrapolation based upon the most recent several seconds of the trajectory (poly 1). The y value of each of the two prediction curves at time t shows the position that was predicted 2 seconds into the future at time t-2. As is typical with time series prediction algorithms, there is a tradeoff between algorithms that respond quickly to changes in recent data values and algorithms that are tolerant of noise.

We tried a number of polynomial prediction algorithms based on various weightings and time windows for the 0th, 1st, and 2nd derivatives of the most recent n seconds of the trajectory. For each prediction algorithm, we used graphical analysis of the predicted trajectories to understand the types of prediction errors characteristic of each algorithm (undershoot, overshoot, lag), and calculated total prediction error across the duration of each trajectory. We empirically determined that the polynomial prediction that exhibited the lowest error was a weighted average of the current position and a linear (1st order) extrapolation of the last several seconds of the trajectory. That is, predicting the trajectory using 2nd order or higher polynomial terms tended to degrade the prediction. The neural network based fuzzy inference system outperformed this "best" polynomial prediction algorithm.

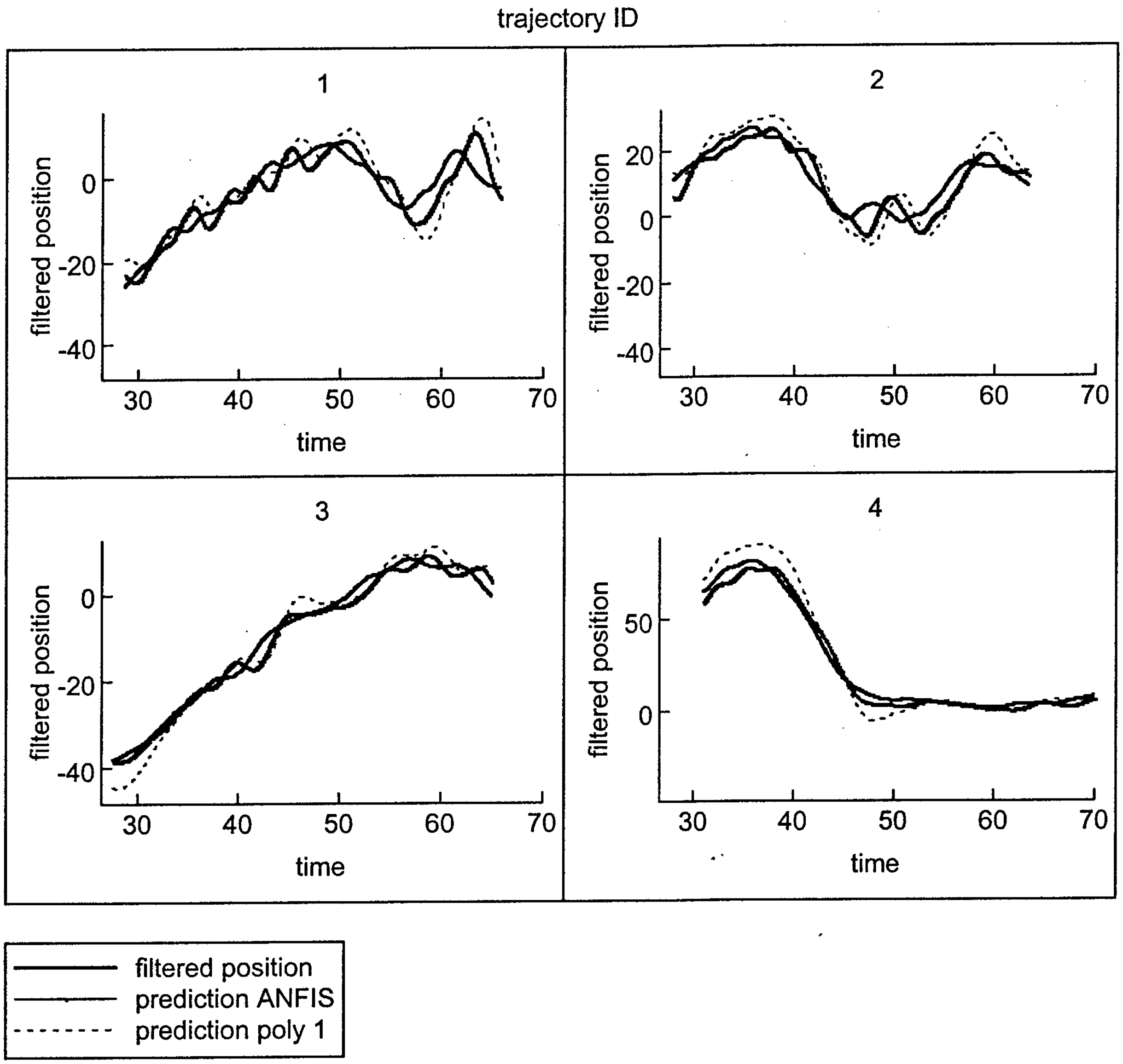


Figure 11. Comparison of neural network prediction with polynomial prediction for four sample trajectories

5 Storyboard Evolution

In this next section we will present the initial storyboard representation and latest representation of the LSO interface produced during the Phase II. In this way, the reader will be able to see how the display evolved over time, and will help the readers understand how the interface display concepts have evolved throughout this project. During this project many iterations of storyboards were created with the specific intent of designing displays that would support the LSOs. Because the interface development process involved many design iterations coupled with multiple sessions of LSO feedback, it would be cumbersome to present all versions of the initial design concepts in this report. Also, while many features will be discussed, not all were considered critical and as such we have included the attached PADAL CD. Each feature that we discuss from the display will have a brief description of its placement, why it is there, and how it evolved.

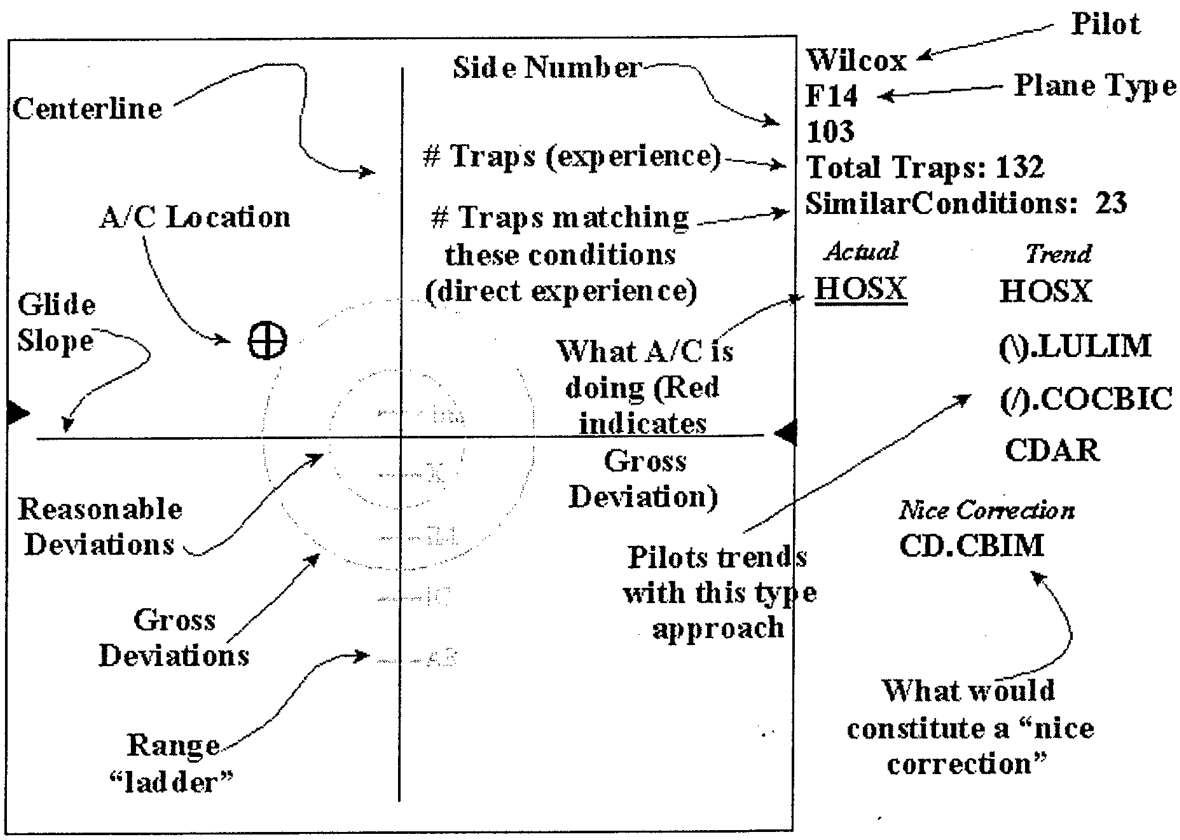


Figure 12. Initial Design

Figure 12 depicts one of the initial concepts for addressing pilot trending in the display. This display should be conceptualized in four distinct areas: The left two-thirds of the display represents current aircraft location with time and distance considerations, the top right-third includes pilot information, the middle right-third shows pilot trends, and the bottom right-third gives the LSO information as to what a "nice correction" would be.

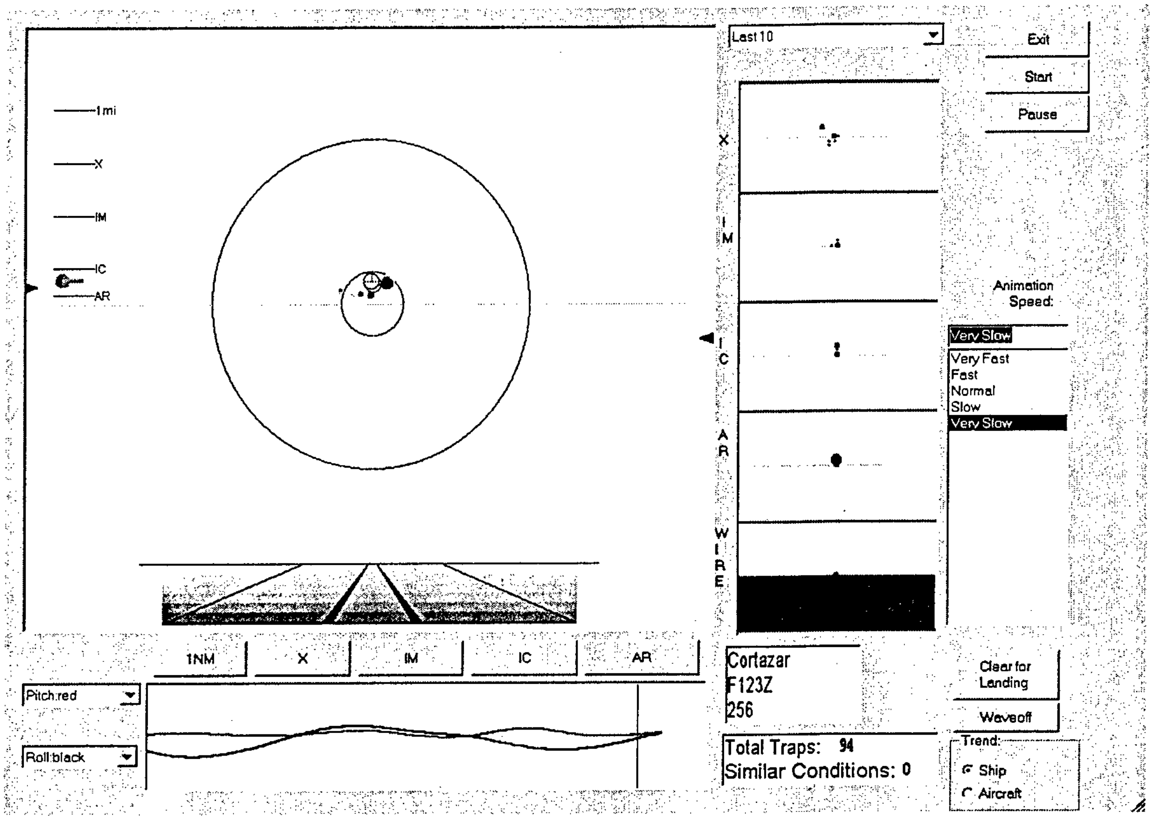


Figure 13. Pilot Trends and Flight Information

One of the later display designs is shown in Figure 13 above. It consists of 4 main portions and the specifications of each are outlined as follows: Incoming flight display with history and prediction of future aircraft position in the upper left two-thirds, deck motion history and prediction by distance from ramp in the bottom left-third, pilot trends by segment in the upper right-third, and pilot information in the far bottom right. Everything displayed to the right of pilot trends and information is for demonstration purposes only. (Note: we recommend that all features can be turned on or off as the user wishes.)

5.1 Potential Sources of Data to Support Display Design Recommendations

While the storyboard designs were being developed we gave considerable attention to the realities of the environment and domain and whether we would be able to acquire the data necessary to implement the display concepts. Figure Y addresses sources of data required for the Graphical Representation (upper left portion of the display area). Figure Z provides the same information for the remaining areas of the display.

While we recognize that much of the data we will need to implement in the displays are already available in one form or another, we feel that we will need better, more consistent data sources to provide us some of the following:a) Today's weather

b) Today's Case I, II, or III
c) Past Passes Information (Advanced APARTS database)

d) Similarity of current pass based on similar condition data
e) Information on relative importance of previous recoveries

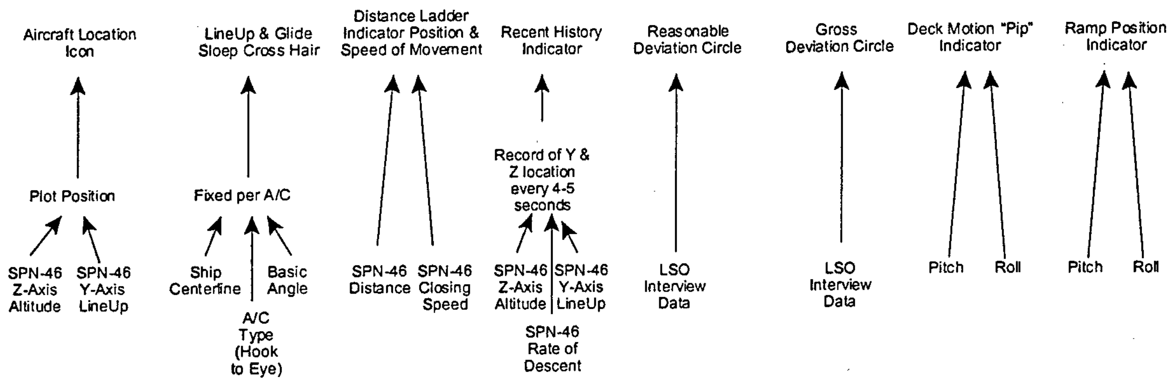


Figure 14. Data sources: Real-time graphs

5.2 LSO Interface Design and Implementation for Pilot Trends

Klein Associates applied decision-centered design to determine the best display options for rapid decision support. The LSO domain is fairly unique in the requirement for the LSO to quickly perceive the likely pattern of motion (the approach). Thus the PADAL system must rapidly convey relevant past cases of approaches.

The interface display is designed to initially be a separate CRT accessible for the CAG/Backup LSO and is not being developed for the Controlling LSO, as was the idea in the Phase I. The goal is to take as much advantage of the expertise of the CAG/Backup LSO, to support this individual's decision making, and to then permit this individual to make the judgment as to whether or not some information should or should not be passed on to the Controlling LSO during actual flight operations.

5.3 Evaluation

Testing and evaluation of the interface concept occurred throughout the development process. Klein Associates was the lead on this task and consulted primarily with Ret. Commander Frank Pfieffer and four LSO instructors at the LSO school in Norfolk, VA. Klein Associates and SHAI visited the LSO school on four separate occasions and talked with over twenty active LSOs about the interface design, focusing specifically on the pilot trending and oscillation recognition aids. We received feedback during each of the four trips (two separate trials), and used the data to enhance features on the interface concept. The evaluation method was an informal process and is described below.

5.3.1 LSO Trials

There were two major LSO Trials. Each trial was conducted using an informal method of evaluation and feedback. The process entailed interviewing highly experienced LSOs about the design concepts followed by LSO reactions to specific features of the design. Each LSO that took part in the trials was instructed to run through the display demonstrations we had built for them and to subsequently provide feedback.

Klein Associates was interested in collecting feedback on many different aspects of the display, which included factors like color, size, and location of features on the display. More importantly though, we were interested in how the information was presented, if it was useful, and if it provided support of their decision making. The trials were not conducted on an actual simulator, however, the LSOs were able to "put themselves in the moment" and comment on potential environmental factors that would effect the use of the interface. They identified factors like sun glare, proper lighting at night so as not to blind them, water on the screen, and effective use of colors so the features would stand out during a quick glance of the screen. In addition to these more peripheral display issues, the first trials, conducted in Decemeber 1999 and February 1999 at the LSO school, primarily concentrated on information produced by pilot trending. And the second trials, conducted in September 1999 at the LSO school, primarily demonstrated the results of the oscillation recognition research and interface implementation. Following each LSO Trial the software was enhanced based on LSO feedback and other results of the trials.

6 Phase II Prototype System

This section describes the design of the PADAL Phase II prototype. The system structure and major components of the PADAL Phase II prototype are detailed below. The system has been deployed utilizing object-oriented design, the C++ computer language on Pentium class hardware under MS Windows operating systems.

6.1 Display Design

The display panel design is as shown in Figure 15 below.

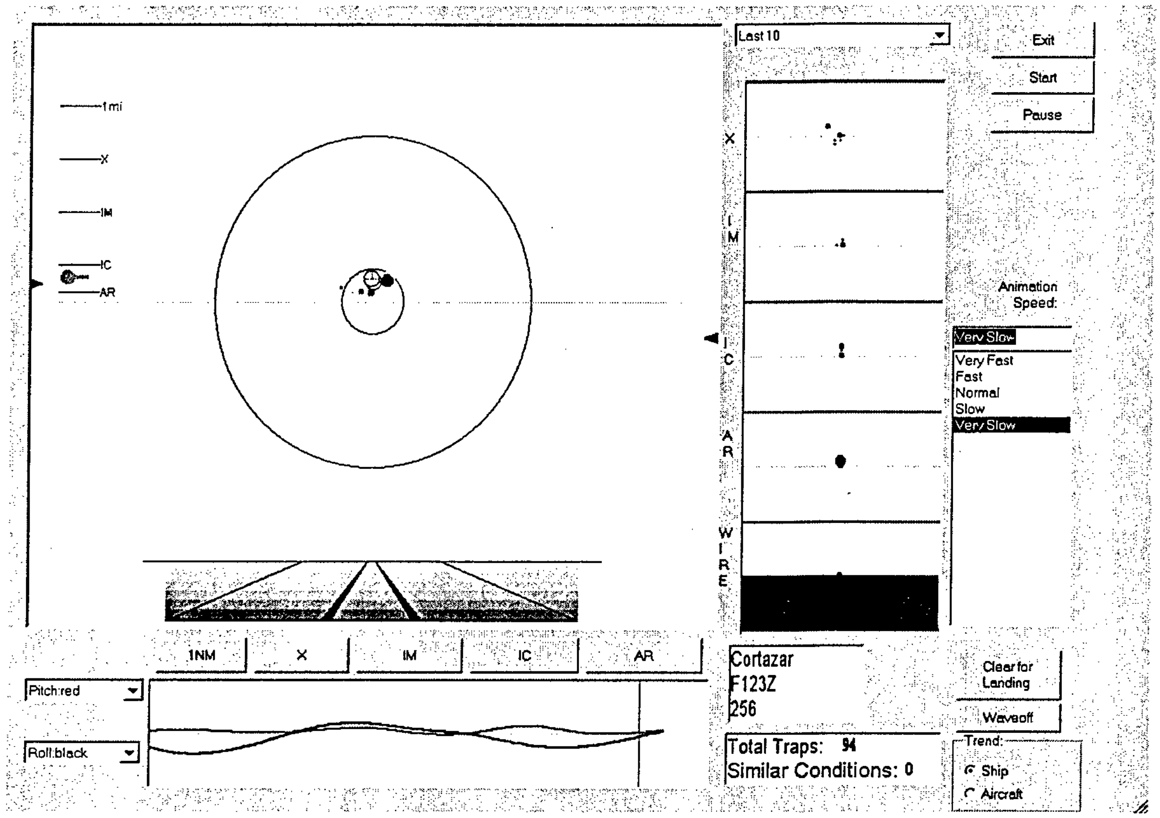


Figure 15. Display panel layout

It consists of 5 main portions and the specifications of each are outlined as follows. This is displayed on the upper left corner of the display panel and can be seen in Figure 16. The features in the display are described below in further detail.

6.1.1 Incoming graphical display

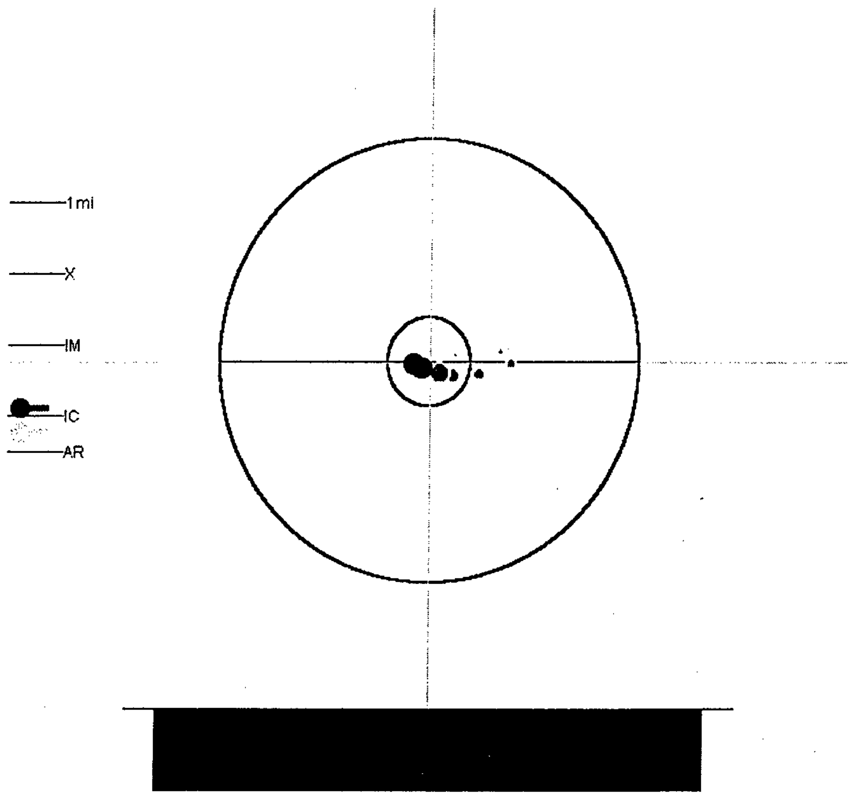


Figure 16. Incoming flight display

This is roughly the 2-D equivalent of the y-z plane of the 3-D trajectory description. A typical incoming flight trajectory in 3-D is as shown in Figure 4.3. The center of the 3-D axes can be considered as the aircraft carrier.

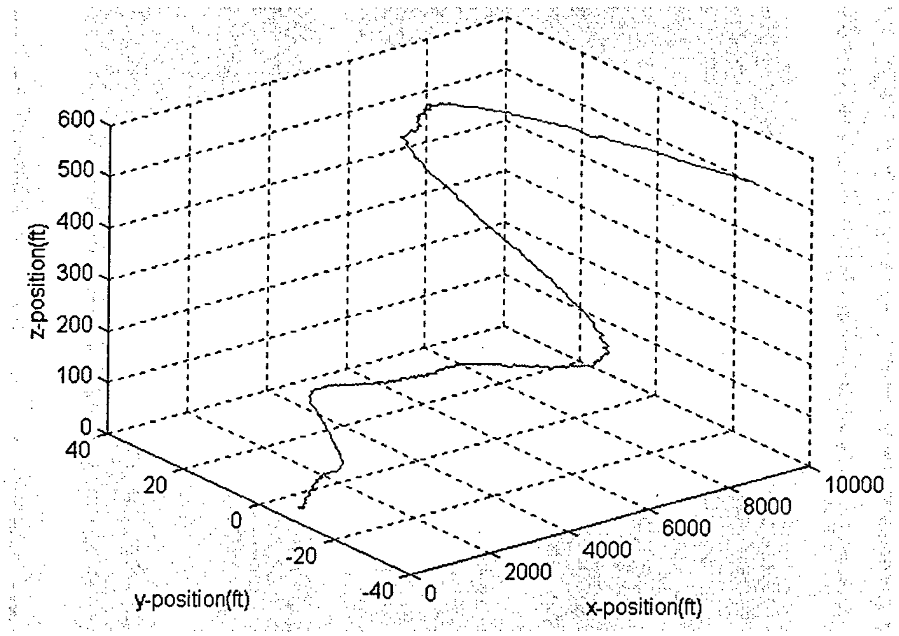


Figure 17. Incoming flight trajectory with coordinate axes center as the aircraft carrier

Glideslope/Lineup Axes and Deviation Circles

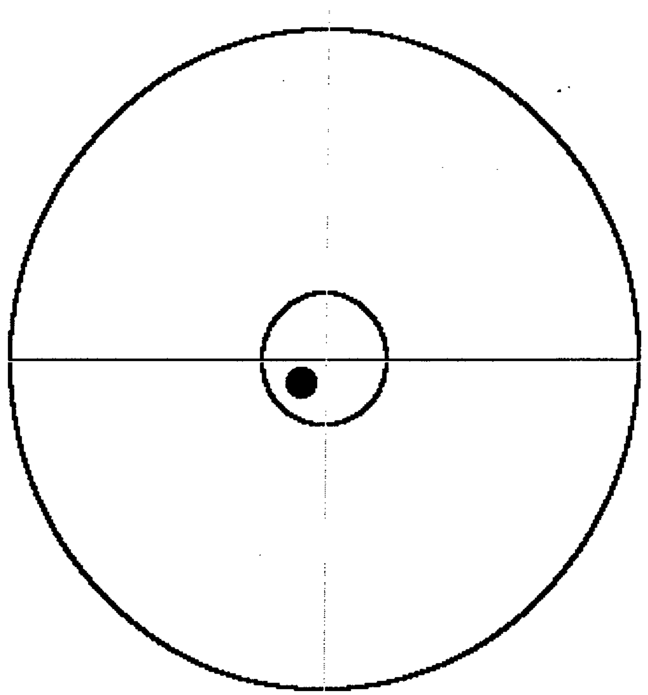


Figure 18. Axes and circles

In Figure 18, the horizontal axis represents the ideal glide slope based on the Basic Angle in effect at the time. Ideally this angle represents 3.5 degrees up and out from the deck and is the path the hook should follow to touch between the second and third wires. The FRESNELL Lens on board ship is adjusted based on the aircraft type to match the particular aircraft hook-to-eye value. The glide slope will be a basic calculated line that may vary some with the specific carrier and is basic angle dependent.

The vertical axis, also depicted in Figure 18, represents the lineup or centerline reference. This line is the actual centerline reference for the angled deck. Exactly how the location of the aircraft is placed with respect to this line will be determined from the SPN-46 radar data and the dynamic centerline.

The overall frame makes up about 60% of the width and about 80% of the height of the display monitor. It is situated in the upper left corner of the display monitor. This feature is similar to what the LSOs see on the PLAT video, a screen they currently use to determine centerline and glideslope deviations as the aircraft approached the deck.

Deviation Circles

Two concentric ellipses represent the thresholds for reasonable and gross deviations. The area bounded by the smaller ellipse corresponds to reasonable deviation and the area outside the larger ellipse corresponds to gross deviation. Because the illustrations in this report are, one cannot see the actual progress from initial concept to the current form.

In the knowledge elicitation, we identified specific quantitative deviations that LSOs would consider to be normal or gross (see Appendix X, data specifics piece), based on each segment of the approach. Because these deviations changed per each segment, the size of the circles would need to change as well. This rationale fed into our initial design where we attempted to incorporate dynamic deviation circles as the aircraft approached the deck. After showing this aspect to many LSOs, the prevailing feedback was to leave the circles static, and to permit the LSOs to make their own calculations in their heads. The LSOs saw circles that are shrinking and increasing in size as more of a distraction than as a support function.

Range ladder

The range ladder as shown in Figure 19 provides the x-position information of the aircraft. The range ladder moves up the centerline as it approaches the aircraft carrier. The actual range of the aircraft is indicated at the crosshair. For example, in Figure 19 the x-position of the aircraft is slightly less than 1 mile from the ship.

Figure 19. Range ladder

This tool is continuously moving, showing the aircraft's location from the ramp in roughly quarter-mile increments. The IC mark is 1/8 mile from AR mark, IM is 1/2 mile from AR mark, X is 3/4 mile from AR mark, and 1NM is 1 mile from AR mark. Each of these reference marks is familiar to the LSOs as they use them for grading segments of an aircraft approach. It should be noted that these are relative reference points and are not regarded as absolute. The range ladder is controlled by the AR mark on the ladder. The AR mark position variable is initialized to be at the bottom of the vertical axes in Figure 4.5 and remains so until the x-position of the aircraft is smaller than 1.25 miles and it will then begin to move dynamically upward.

The position of the range ladder has changed significantly from the initial design concept where it was seated in the center of the incoming graphical display as seen in Figure 1.2.3.4.5.6. Many of the LSOs found this to be distracting and also commented that it cluttered the screen. Because many of them liked the feature so much, a solution was to move it to the left, as seen in Figure 4.2, where it could be quickly viewed and unobstructed from other dynamic features. The range ladder still utilizes the horizontal axis as a reference point of location.

State of the Deck

Colored markers are shown in the range ladder to indicate the state of the deck. The position of the mark on the range ladder is an indication of where the pilot may be waved off if the status of the deck does not change. State of the deck was not considered in the initial design concept but was seen as an important feature to include after frequent discussions with the LSOs. In addition, many of the latest accidents at sea have occurred because the deck was not clear or set for safe landings. Interestingly, a warning does appear on the current LSO workstation, but no warning exists for the 100 and 10 foot standards that must be met for clearing a foul deck and a deck not set for traps (wires are not retracted).

- A red mark  indicates a foul deck (i.e., the deck is not ready and the LSO may need to wave off the pilot in order for the aircraft to clear the ramp at the 100-ft. standard).

- An amber mark indicates the equipment is not set for the trap. It shows at what point the LSO must wave off the pilot in order to clear the 10-ft. ramp clearance standard.
- The amber mark will turn green (i.e.,), to indicate the deck is clear and ready for landing.

These again are just reference points and are not absolute values. Many other factors like aircraft weight and configuration to name a few affect when and where an aircraft can be waved-off. Many of the LSOs are very sensitive to having a computer determine where a wave-off can occur without taking into consideration the many other factors that would affect the clearance of the 100 and 10 foot standards. However, given the recent accidents that have happened we still feel a warning is necessary, whether it be relative or not.

Incoming flight position

A small red solid circle as shown in Figure 4.6 indicates the current position of the aircraft. The position variable is governed by the current reading of lineup and glideslope deviation (taken from SPN-46 radar data). This is permanently displayed on the panel as a dynamic feature. This is a critical piece of information since it is required before we can look at any trends and/or oscillations. We have to be able to track where the aircraft currently is to be able to do any of these. By being able to track the aircraft's current location we are able to:

- Identify where the aircraft has been in the past
- Identify where the aircraft is with respect to glideslope
- Identify where the aircraft is with respect to lineup or centerline
- Translate this information (past and present) into pilot trends and to provide history for the entire pass.

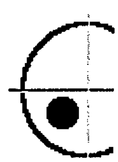


Figure 20. Current aircraft position

This particular feature is the basis for all items listed above. We intentionally use a solid circle for several reasons: not to inadvertently give any impression of knowledge about wing position (up, down, etc.), so it can be easily recognized on the screen with the other features, and so that it shows up in a sun glare.

Recent aircraft trajectory profile

To display the history of what the aircraft has done, seven gray dots of diminishing (increasing?) sizes are displayed on the panel to represent the recent 7 positions of the aircraft. An array of 7 variables is used for this representation and each member of the array corresponds to:

aircraft_profile[0] : the position of the aircraft at t -35 sec.
aircraft_profile[1] : the position of the aircraft at t -30 sec.
aircraft_profile[2] : the position of the aircraft at t -25 sec.
aircraft_profile[3] : the position of the aircraft at t -20 sec.
aircraft_profile[4] : the position of the aircraft at t -15 sec.
aircraft_profile[5] : the position of the aircraft at t -10 sec.
aircraft_profile[6] : the position of the aircraft at t -5 sec., where t is the current time.

Starting with aircraft_profile[0], then aircraft_profile[1], ..., and , aircraft_profile[6], each is displayed on the screen, remaining on the screen for about two seconds. Many variations of this feature were talked about with the current design being the most comfortable for the LSOs. Many were concerned with screen clutter and the dynamic nature of the design being distracting, but most were satisfied with the current design. The LSOs thought that the history could be picked up by a quick glance of the screen without having to wait long for the history to be displayed. Because it is difficult to represent the dynamic nature of this in the report it is recommended that the reader look to the CD for a good demonstration.

6.1.2 Pilot Trending

<u>*Pilot information*</u>

The pilot name, aircraft type/model, and side number is displayed in the middle portion of the display panel. It has the following format:

Pilot name: String (e.g., Wilcox)
Aircraft type: String (e.g., F14B)
Aircraft side number: (e.g., 103)

This is just the basic information about who is flying, what is flying, and which specific aircraft it is – all important for the LSO to know. The pilot's name conveys a lot of information to the LSO <u>when</u> it is a pilot who is part of their squadron or wing <u>and</u> they have been deployed for a long enough for the LSOs to become familiar with how the individual flies. If it is during carrier qualifications or it is a pilot who is not part of their unit (i.e., COD pilots, etc.) then less information is conveyed, other than it's a pilot they do not know.

The other information shown is already available to the LSO but we feel that is doesn't hurt to repeat it. The main concern, however, is that a pilot may be "swapped" out for the day's flight and what is shown is not accurate. We have to assume there will be some way to verify who the pilot actually is. One other important note to mention is that the pilot name being displayed has undergone some serious criticism in the past. Two years ago a name could never be displayed on the workstation due to ??? But because of a changing culture and philosophy within the Navy, and in particular the LSO community, the name being displayed is no longer a negative issue and is actually seen as a helpful feature to the LSOs.

The Last 10 profile

Initially we wanted to see how the aircraft was approaching the carrier and give trends for the approach, based on how this particular approach started. However, the LSOs asked that we just show the pilots' regular trend under the particular conditions for the current pass (e.g., night landings in F/A-18B). They have also asked that pilot trends be flashed up all at once as opposed to sequentially as the aircraft passes each segment of the approach.

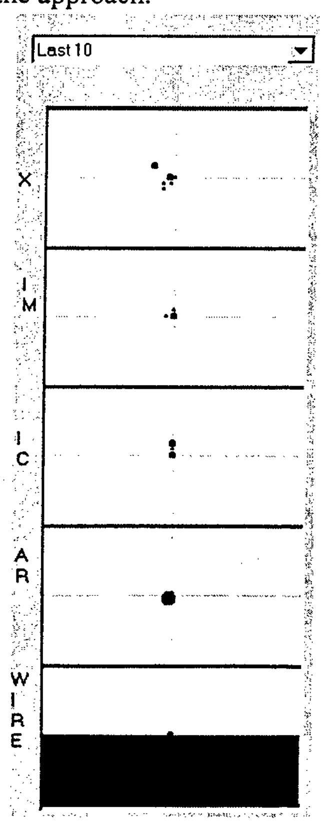


Figure 21. Example of Last 10 scatter plot trend

In figure 21, the right hand portion of the display shows current and trend data in the form of LSO grades/comments. In our currently display we have five square windows with cross-axis line-up in a column to the right of the incoming flight graphical display. It occupies about 15% of the total screen width as shown in the figure below.

The reason for the transformation to a scatter plot was due to the feedback received from the LSOs. Many of them found the grading and comments cumbersome to read, and many generally like the look of the scatter plots.

Trend analysis can provide the LSO with some very useful information. However, in order to guard against the possibility that the pilots "trend", or average, might equate to a zero and give the LSO no trend information at all, we have inserted a scatter plot for specific sections of the approach (at the start, IM, IC, AR, and I/OW). In figure 21, each scatter plot displays the pilot's last ten passes under similar conditions (night, case 3, etc.). The current flight position is indicated by a relatively large round red dot, the rest of the ten recent dots have varying sizes indicating their recency. The most recent one is larger.

The scatter plots allow the LSOs to examine what a pilot has done in their last ten passes, which in some instances can give them more information than just the "trend." In addition, it allows the LSO to quickly identify deviations in a pilot's past performance and match them up with what is currently happening. As the pilot enters each section of the pattern, the scatter plot identifies three approaches from last ten passes that closely match the current position of the aircraft. Three distinct circles appear in the upper right quadrant of the plot signifying three similar starts. From this point, the LSO is able to follow these circles in each subsequent scatter plot. It is important to be able to follow these circles because the purpose of the plots is to give the LSO a picture of how this pilot looked in sequence as they made the approach to the ramp during past approaches.

The Last 10 column is also shared by a similar 10 feature and APARTS trend data. The Similar 10 feature was developed using CBR and is another way to represent pilot trends. Although it is more complicated than the Last 10, similar 10 concept is based on the initial idea of how the aircraft is approaching
the carrier, and to give trends for the approach based on how this particular
approach started. This is a useful feature when a pilot, usually more experienced, flies many passes. If s/he always overshoots the start, the LSO can look at the trend data on the scatter plot to see what s/he normally does in the subsequent segments of the pass.
The LSOs saw the APARTS data as extremely useful because they use the tool all the time. The APARTS database is a tool that the LSOs use to enter grading/comments for pilots, and has its own trending system based on day or night landings. However, because the APARTS database is not a complete database that is updated, many of the LSOs would not find it useful on deck.

6.2 Interface to LSO Simulator

PADAL has been designed, implemented and tested to interface with the LSO Training Simulator. That is, PADAL can receive its data from stored information on disk or can receive live pass information via ethernet and receive data from the LSO Training Simulator.

7 Deliverables

The PADAL CD contains:

- PADAL Software, and the
- PADAL User's Manual.

8 Phase III and Future Work

There are enormous opportunities for the Department of Defense to make use of the results of this effort, both directly and indirectly. Most directly, the LSO is the direct target for this effort. Furthermore, the ability to safely direct the landing of helicopters is an important capability for almost all Naval platforms. Many of the techniques used to develop the PADAL System can be applied to other platforms as well.

As shown in the following figure, a portion of the PADAL Phase I and Phase II research will be incorporated into the VISUAL system and thus the LSO workstation software, running on the LSO's workstation hardware. In particular, portions of the technology developed for PADAL has already been incorporated into the VISUAL system.

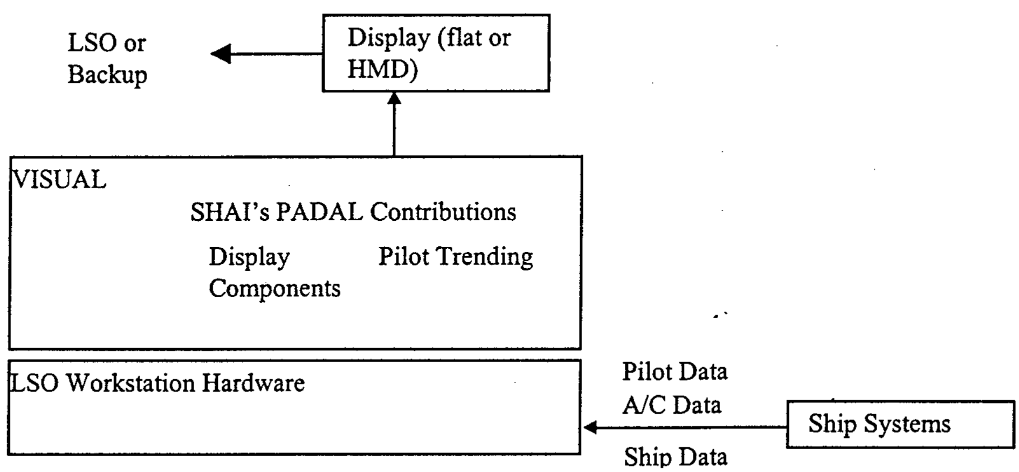


Figure 22. PADAL Context

Besides the contributions PADAL has already made to the VISUAL system, there are important areas where Phase III work could add to these contributions.

1) Provide PADAL in a continuous training environment
   Allow for continuous LSO Trials. That is, a working PADAL would remain with the LSO Trainer (the interface has been completed during Phase II work). This task would allow for more realistic testing of the various PADAL components to better judge there utility and thus to determine which components should be integrated with VISUAL. Users would have the option to view or not view PADAL. LSO would provide feedback after using the entire trainer and note whether they ever used PADAL, and if so what was found to be useful. A final test would be to remove PADAL from the LSO Trainer environment after many LSOs had become familiar with it and measure reaction to its absence.

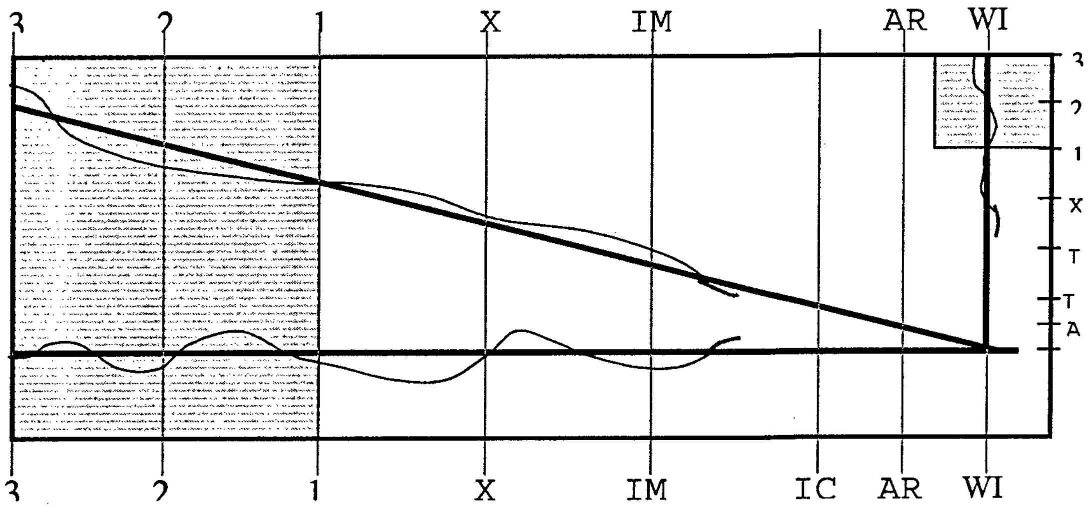
2) Test PADAL at sea or the carrier landing practice field
Conduct a LSO Trail on an aircraft carrier or at the carrier landing practice field, in a non-obstructive manner.
3) Cone for showing prediction of ship
Continue to develop the ship-motion-prediction algorithm to provide a cone of prediction. It is difficult to predict the four second hence deck location due to the limited information provided for prediction, however, the prediction could be enhanced by providing a cone of prediction as shown below. The thick

Figure 23. Prediction Cone

black line is the past motion with the present position shown at the rightmost side of the line; the prediction cone shows the range of possible locations the deck may take during the next 4 seconds. The cone would be much more descriptive than the example shown, for it could be color shaded to represent the likelihood of the deck being in a certain part of the cone.
4) Improve plane-prediction algorithm (with more data)
Continue to develop the plan-prediction algorithm. This development is critically dependent on more landing data. With more landings the present algorithms can be further tested and enhanced. In addition, the prediction can be modified from a point prediction to a range prediction where the future location of the plane is represented to show a region where the plane will most likely to be. This is similar to the proposed modification to the ship-motion prediction.
5) Offline version with playback capability
LSOs have requested a playback capability for debriefing, review, and instructional purposes. Requested features in the playback version include pause, random playback at any stage, and slow/fast play. It is also preferred that the offline version is network accessible with password protection in different levels.
This capability has been requested at all the LSO Trials and during the PADAL Q&A session at the OAG meeting. This playback capability could be first implemented via the LSO Trainer, such that whenever the system is attached to the LSO Trainer all passes would be recorded for later playback.
6) Ramp motion alarm
LSO requested an alarm if the ramp motion exceeds 8 ft/second; also alarm if ramp motion 'changes significantly'. The specifics of *change significantly* would need to be elicited from the LSO community.
7) Adaptively learn ranges corresponding to LSO shorthand comments
The ranges of deviation corresponding to the various LSO shorthand comments where determined from knowledge elicitation from various LSOs, and implemented using fuzzy system approach. The actual ranges may be different in actuality than as described on dry land and the ranges may change over time and under different conditions.
PADAL could be modified to adaptively learn and update the fuzzy system for determining the appropriate ranges that correspond to the LSO shorthand comments. The information used to learn

the ranges could also be used to graphically depict via a scatter plot the actual aircraft location versus LSO comments. This could be used as a training and review tool.

8) Unified Aircraft Glideslope, lineup and ship deck pitch display with predictions
In the figure below, the gray areas are present to indicate a different scale. These indicate 2 miles, while the entire remainder of the display concentrates on that last mile. As we have been doing, we would still provide predictions for the a/c glide slope, lineup and the deck motion (shown in red in the figure). So we get history, actual, and predicted for these three. The focus would be to take this initial integrated display concept and hone it to create one integrated display that provides valuable



information and can be quickly comprehended.

In addition to the LSO specific applications, the advanced motion case display technology developed for LSOs would be useful in domains where past cases of motion patterns can be retrieved and when this historic data must be quickly conveyed to the user. One example is threat assessment in complicated tactical scenarios (especially those related to defense) such as those faced by the E2C officer, the AAWC (Anti-Air Warfare Coordinator) in the CIC, and the Weapons Director aboard an AWACS. SHAI has contacts in all of these fields.

9 Conclusions

This report has summarized the tasks and results of this Phase II SBIR project. The project utilized artificial intelligence and cognitive task analysis to develop a LSO driven decision support tool.

The project determined the significant aircraft approach parameters and similarity measures and important pilot considerations and similarity measures. From this information the project developed pilot trending techniques and software using case-based reasoning and combinations of other AI techniques. In addition, in conjunction with many LSOs, the project determined the best display options and most appropriate display logic for the information produced by the pilot trending and oscillation recognition modules, and designed and implemented the resulting LSO interface.

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Certification of Technical Data Conformity (May 1987)

The Contractor, Stottler Henke Associates, Inc., hereby certifies that, to the best of its knowledge and belief, the technical data delivered herewith under Contract No. N68335-98-C-0027 is complete, accurate, and complies with all requirements of the contract.

Signature

Melissa Thiemmedh

Name - printed

Lead Accountant

Title

January 28, 2000

Date

Appendix A

Segment: 180E (Case I & II) or 3 NM from the ramp (Case III)

	Case	**How Can Deviate (e.g., high/low; left/right)**	**Indicators (e.g., angle of bank, altitude, etc)**	**Specific Cues/Indicators (e.g., how much right wing tip is visible, how big the aircraft looks)**	**Discrimination Ability (e.g., ±30 ft above G/S, ±5 kts) [1]**	**When does Deviation "Become a problem?" (e.g., 75 ft. .low)**	**Differences for Pilots/Pilot Types?**
Glide Slope/Glide Path 1200 ft. descent begins	I	High/Low	Altitude	Altitude relative to horizon or other reference point. + perception.	+/- 50 feet	-100 ft. low	FNG - significant AVG - possible Top - wouldn't expect the error
	II	same	same	same	same	same	same
	III	Note: acft is intercepting G/S from level flight at 1200 ft.	same	Same + CCA [2] controller calls / HUD indicators	± 200 ft. with horizon and/or relative height to other acft.	Same - see note [16]	same
Attitude/Speed	I	Too fast/Too slow TCA - too close abeam. Speed and power usually up; wrapped up	The acft's attitude.	The nose up/down; tilt of the acft. It's attitude.	+/- 5 kts *judged relative to what the particular acft's desired speed is.*	> + 15 kts > _ 10 kts	same
	II	same	same	same	same	same	same
	III	same	Appr lights (AOA) [3] Nav lights (AOA + wingtips)	Appr. lights: Green (slow), Amber (on speed), Red (fast); Nav lights		same	same
Line Up	I	TCA- too close abeam. TWA-too wide abeam Baseline is 1.5 mi. abeam	Distance from ship	Size of acft	± 1/4 NM	>± 1/4 NM	same
	II	same	same	same	same	same	same
	III	Left/Right of C/L	Left/Right of perceived C/L & CCA calls [4]	Relative to ref. point, other acft and no other cues.	± < 500 ft. Right or Left (at 3NM)	No corrections made, drift back and forth	same
Configuration of aircraft	I	Gear, Flaps, Hook Up/Down	Visually see acft configuration	See acft gear, hook, flaps	See gear, hook flaps up or down. Cannot see if they are partially down unless one gear is not down.	Any of these not in their proper configuration for the acft	No difference
	II	same	same	same	same	same	same
	III	same	Lights on acft at night	Approach light on and steady. [5] Gear & hook down. Other lights depend on acft type.	LSO sees light [5]	Lights not working requires a low fly by.	same

Appendix A

Segment: 135E (Case I & II) or 2 NM from the ramp (case III)

	Case	How Can Deviate (e.g., high/low; left/right)	Indicators (e.g., angle of bank, altitude, etc)	Specific Cues/Indicators (e.g., how much right wing tip is visible, how big the aircraft looks)	Discrimination Ability (e.g., ±30 ft above G/S, ±5 kts)	When does Deviation "Become a problem?" (E.g., 75 ft. .low)	Differences for Pilots/Pilot Types?
Glide Slope/Glide Path 900 ft. descent established	I	High/Low	Altitude, starting to descend	Altitude relative to horizon or other refer. point.	±50 ft.	±75 ft.	FNG - significant AVG - possible Top -possible
	II	same	same	same	same	same	same
	III	same	same	CCA calls and same as above	± 100 with refer. point	± 150	same
	I	Too fast/slow	Speed, about the same as at the 180E	Nose up or down	± 5 kts	> ± 10 kts and/or not stable	same
	II	same	same	same	same	same	same
Attitude/Speed	III	same	Appr lights and Nav light (attitude)	Lights and perception of attitude.	± 3 - 5 kts appr light ± 8 - 10 kts attitude lights	same	same
	I	Too much or too little AOB	AOB of acft in the turn	Tilt of wings. Outside wing height relative to inside wing	Amount of wing seen is different for various acft. [6]	Deviations will vary widely, but leads to possible critical decision at or after the 90E	All essentially the same regardless of experience
	II	same	same	same	same	same	same
Line Up	III	Left/Right of C/L and steady or drifting Left/Right of C/L	Left/Right of perceived C/L and CCA calls [4]	Relative to refer. point or other acft; no other cues	± 200 ft Right/ Left at 2 NM	Consistent error Left/Right or drift back and forth	FNG - significant AVG - probable Top - probable
	I	Visually see aircraft configuration	See acft gear, hook, flaps	See gear, hook, & flaps up or down.	same as 180E	Not dirty	No difference
	II	same	same	same	same	same	same
Configuration of aircraft	III	same as at 3 NM	Lights on acft at night	Appr light on and steady Other lights - acft type	LSO sees light [5]	Lights not working, requires low fly by.	same

Appendix A

Segment: 90E (Case I & II) or 1 NM from the ramp (case III)

	Case	How Can Deviate (e.g., high/low; left/right)	Indicators (e.g., angle of bank, altitude, etc)	Specific Cues/Indicators (e.g., how much right wing tip is visible, how big the aircraft looks)	Discrimination Ability (e.g., ±30 ft above G/S, ±5 kts)	When does Deviation "Become a problem?" (E.g., 75 ft. .low)	Differences for Pilots/Pilot Types?
Glide Slope/Glide Path First point at which the pilot can see the ball for Case I & II. Should start to " flying it" a little. 600 ft. Descent "stable"	I	High/Low	Altitude + descent rate	Perception of rate of descent (ROD) above or below normal; Relative to perceived G/S	± 300 fpm from norm [7] ± 25 ft [10]	> 50 ft. Low	FNG -Significant AVG - possible Top- possible
	II	same	same	same	same	same	same
	III	same May settle at first "glance" at ship [8]	same	same + CCA calls and HUD [9]	± 300 fpm ± 50 ft. [10]	same	same
Attitude/Speed	I	Fast/Slow	Speed	Nose attitude combined with roll as a pilot makes greater corrections to roll wings for intercepting C/L	Difficult to judge. Specifically due to greatest roll corrections [11]	> ± 10 kts Gross change	FNG - significant AVG - probable Top - probable
	II	same	same	same	same	same	same
	III	same + inconsistent or not stable	Appr lights - red, amber, green Nav lights - attitude	Lights and perception of attitude	± 3 - 5 kts appr light ± 8 - 10 kts attitude light	> ± 8 kts	FNG - significant AVG - probable Top - possible
Line Up	I	The acft's turn with respect to its position in the turn can bring it in Left/Right of C/L	AOB and aircraft's position relative to the X	The tilt of the wings (outside up, inside down) and the acft's physical position in the turn towards the X	± 5E- 10 AOB required to complete turn to line up at X	If AOB required exceeds 45E(excessive) to prevent over shoot or AOB < 150E to prevent undershoot. [13]	FNG - very signif. AVG - signif. Top - probable
	II	same	same	same	same	same	same
	III	Lined up Left or Right of C/L [8] Drifting Left or Right of C/L	Left/Right or drifting Left/Right of perceived C/L + CCA calls + movement of wings	Perception, PLAT, HUD, CCA calls, wing movement	± 100 ft. Right/ Left at 1 NM	> 100 ft. Right/Left or inconsistent/drifting with no correction.	FNG - significant AVG - significant Top - possible
Configuration of aircraft as well as sequence/separation	I	Gear, flaps, hook not down	Visual	Visual	Down or Up	Not dirty	FNG AVG <u>No differences</u> <u>Top</u>
	II	same	same	same	same	same	same
	III	same	Lights on acft	Appr light on and steady; other lights depend on acft type	See note [5]	Lights not correct	same

Appendix A

Segment: X (½ - 3/4 NM astern)

	Case	How Can Deviate (e.g., high/low; left/right)	Indicators (e.g., angle of bank, altitude, etc)	Specific Cues/Indicators (e.g., how much right wing tip is visible, how big the aircraft looks)	Discrimination Ability (e.g., ±30 ft above G/S, ±5 k/h)	When does Deviation "Become a problem?" (E.g., 75 ft. .low)	Differences for Pilots/Pilot Types?
Glide Slope/Glide Path	I	High/Low Deviating High - low/ Low- high	Perception of relative G/S, altitude, ROD	Perception of ROD + engine power (exhaust, sound)	± 200 fpm from normal ± 25 ft	> 50 ft high < 25 ft. low or Unstable/Inconsistent	FNG - signif. AVG - possible Top - possible
	II	same	same	same	same	same	same
	III	same	Perception - using ramp as horizon	same + HUD	same	same	same
	I	Fast/Slow; deviating fast or slow to on speed, back and forth	Speed /AOA	Perception of attitude, appr light, Power Degrees pitch = attitude	± 3 - 5 kts ± 3E- 5Eis discernable	> 10 kts too fast or unstable > 5 kts to slow	FNG - signif AVG - possible Top - possible
	II	same	same	same	same	same	same
Attitude/Speed	III	same	All cues from Nav lights and appr light	same	same	> 5 kts to fast or slow or unstable	same
	I	Left/Right, drifting L/R, Correcting Left/Right to C/L	Perception of Left/Right of C/L; Wing down	PLAT, perception relative to peripheral sense of ramp/ship	75 ft. Left/Right of C/L	> 75 ft. Left/Right of C/L or drifting with no corrections	FNG - signif AVG - signif Top - Probable
	II	same	same	Degree of wing movement; Length of time wings are down.	same	same	same
Line Up	III	same	All cues from Nav lights and appr light	same + addition of HUD	same	same	same
	I	Gear, flaps, hook not down	Visual	Visual	Flap configuration can be confirmed at this point		No difference
	II	same	same	same	same		same
Configuration of aircraft as well as sequence/separation	III	same	Lights	Lights	See note [5]		same

Appendix A

Segment: IM (1/4 NM astern) Wave off window may start here.

	Case	How Can Deviate (e.g., high/low; left/right)	Indicators (e.g., angle of bank, altitude, etc)	Specific Cues/Indicators (e.g., how much right wing tip is visible, how big the aircraft looks)	Discrimination Ability (e.g., ±30 ft above G/S, ±5 kts)	When does Deviation "Become a problem?" (E.g., 75 ft. .low)	Differences for Pilots/Pilot Types?
Glide Slope/Glide Path	I	High/Low, B(flat/shallow) G/P, Deviating High to low/ Low to high	Perception of deviation from G/S; ROD deviation/ power correction	ROD variances, Power, sound, exhaust, smoke	± 100 - 200 fpm ± 20 ft. from G/S	> 40 ft high > 20 ft low	In the case of large or no corrections FNG - probable problem IC, AR
	II	same	Power	ND (nose down) Movement relative position to G/S (above, below, on)	Any nose movement [14] ± 20% of power required	> ± 300 fpm Rapid changes in ROD Unexpected ROD changes	AVG - possible problem IC, AR Top - Possible - probable(see note IM)
	III	same	Power	same + HUD	same	Inappropriate use of nose. Over-controlled power	same
Attitude/Speed	I	Fast/Slow Deviating Fast to slow/Slow to fast	Attitude Appr light	Attitude changes Appr light	3 - 5 kts ± 3E- 5E pitch	> 10 kts fast > 5 kts slow	same
	II	same	same	same	same	same	same
	III	same	1st point at which LSO can clearly see entire acft and therefore see attitude clearer than with lights alone	Position of appr light with respect to Nav lights; Appr light alone	same	same	same
Line Up	I	Left/Right , Drifting Left/Right, correcting Left/Right to C/L	Perception of acft with respect to C/L. Wing movement	Perception of displacement and drift. Rate, degree, & duration of roll	± 50 ft Left/Right ± 3E- 4E Heading variance	> 50 ft Left or Right; rapid drift; uncorrected drift or L/U error	same
	II	same	Acft drift including wing movement	% PLAT	± 2EAOB	> 10E AOB for > 1 - 1.5 seconds > 5E Heading change	same
	III	same	same	% HUD	same	same	same
Configuration of aircraft as well as sequence/separation	I	Flaps not set correctly for landing visual	Visual	Visual: acft is close enough to fully view landing flap setting	Set properly or not	If not set, is wind over deck high enough to accept acft at the high closure speed? If not, W/O	No difference
	II	same	same	same	same		same
	III	same	same	Same See note [15]	same	Also can check closing speed from HUD to determine if acft is below max trap ground speed.	same

Appendix A

Segment: IC (1/8 NM astern)

	Case	How Can Deviate (e.g., high/low; left/right)	Indicators (e.g., angle of bank, altitude, etc)	Specific Cues/Indicators (e.g., how much right wing tip is visible, how big the aircraft looks)	Discrimination Ability (e.g., ±30 ft above G/S, ±5 kts)	When does Deviation "Become a problem?" (E.g., 75 ft. .low)	Differences for Pilots/Pilot Types?
Glide Slope/Glide Path	I	High, HCD, B, Low, LoB (low and flat),	Acft movement/change in ROD, nose movement, power	Rate of ROD changes as well as ROD itself.	± 100-200 fpm ± 10 ft	> 20 ft high > 10 ft low > ± 200 fpm	FNG - outside limits: W/O.
	II	Fly through the G/S. Also, climb (C) & settle (S)	Power	Degree & duration of ND; Degree & duration of power (changes in sound, exhaust)	Any nose movements 10% - 2% of power required	Any ND > 3 - 5E & correct Any power change > 25% of required power	AVG - outside limits but correcting: (OK) Top - outside limits: possible W/O & unexpected
	III	same	same	same	same	Any rapid ROD change	W/O for all deviations x²
Attitude/Speed	I	Fast/Slow Deviating Fast to slow/ Slow to Fast	Appr light Attitude changes	Pitch changes; Appr light changes	0 - 5 kts Improper landing attitude w/out regard to A/S	> 5 kts change > ± 3 - 5E pitch	FNG - if rough AVG - outside limits but correcting: (OK) Top -same as AVG
	II	PNU -improper G/P control DN - (Drop nose) loss of attitude control ND - improper G/P control	same	At this point attitude is more important for G/P and landing attitude	Improper G/P correction ± 3 - 5E of pitch	± 5 kts to fast/slow	
	III	same	same	same			
Line Up	I	Left/Right of C/L Drifting Left/Right	Perception, PLAT, DW (drop wing) as with DN	Perception of displacement; Perception of rate of drift; Degree of wing down before displacement	25 ft Left/Right 2 - 3E of heading	> 25 ft > 5E AOB >½ - 1 sec	FNG- outside limits W/O AVG - same Top- not expected
	II	Correcting back	same	same	± 2E AOB	> 2 - 3E heading change Any drift not being corrected	same
	III	same	same + HUD to a lesser degree	same	same	same	
Configuration of aircraft as well as sequence/separation	I						
	II						
	III	No appr light	No appr light	No appr light	On or off	W/O for fly by gear check	

Appendix A

Segment: AR (At the ramp)

	Case	How Can Deviate (e.g., high/low; left/right)	Indicators (e.g., angle of bank, altitude, etc)	Specific Cues/Indicators (e.g., how much right wing tip is visible, how big the aircraft looks)	Discrimination Ability (e.g., ±30 ft above G/S, ±5 kts)	When does Deviation "Become a problem?" (E.g., 75 ft. .low)	Differences for Pilots/Pilot Types?
Glide Slope/Glide Path	I	same as IC	same as IC	same as IC	± 100 - 200 fpm ± 10 ft	> 10 ft high > 5 ft low > 200 fpm	Any major variance for any pilot deserves attention
	II	same as IC	same as IC	same as IC	Any nose movement ± 10% of power	Rapid or sudden change in ROD	same
	III	same as IC	same as IC	same as IC	same	Any DN or ND, over-controlled power	same
Attitude/Speed	I	same as IC	Attitude alone (A/S will not change appreciably AR - IW?)	same as IC	± 2 - 3E of proper attitude	> 3E pitch	same
	II	same as IC	same	same as IC	same	same	same
	III	same as IC	same	same as IC	same	same	same
Line Up	I	same as IC	DW, Drift	same as IC except...	± 10 - 25 ft ± 2 - 3E heading variance	> 15 ft > 3E AOB > ½ second	same
	II	same as IC	Uncorrected correction (PLAT drops out)	...Drop PLAT...	± 2E AOB	> 2E heading variance. Any uncorrected drift	same
	III	same as IC	same	...Drop HUD	same	same	same
Configuration of aircraft as well as sequence/separation	I						
	II						
	III		<	Back up LSO is shining Aldis Lamp (hand-held search light) on acft landing gear during low fly by.	>		

Appendix A

Segment: IW or OW (In the wires or over the wires) Too late for any LSO intervention other than an attitude call to set the hook or call a bolter to the pilot.

	Case	How Can Deviate (e.g., high/low; left/right)	Indicators (e.g., angle of bank, altitude, etc)	Specific Cues/Indicators (e.g., how much right wing tip is visible, how big the aircraft looks)	Discrimination Ability (e.g., ±30 ft above G/S, ±5 kts)	When does Deviation "Become a problem?" (E.g., 75 ft. low)	Differences for Pilots/Pilot Types?
Glide Slope/Glide Path	I						same for all pilot types
	II						same for all pilot types
	III						same for all pilot types
Attitude/Speed	I	ND	ND	ND	2 - 3E	> 2 - 3E	same for all pilot types
	II	same	same	same	same	same	same for all pilot types
	III	same	same	same	same	same	same for all pilot types
Line Up	I						same for all pilot types
	II						same for all pilot types
	III						same for all pilot types
Configuration of aircraft as well as sequence/separation	I						same for all pilot types
	II						same for all pilot types
	III						same for all pilot types

Appendix B: Corollary Grid Notes

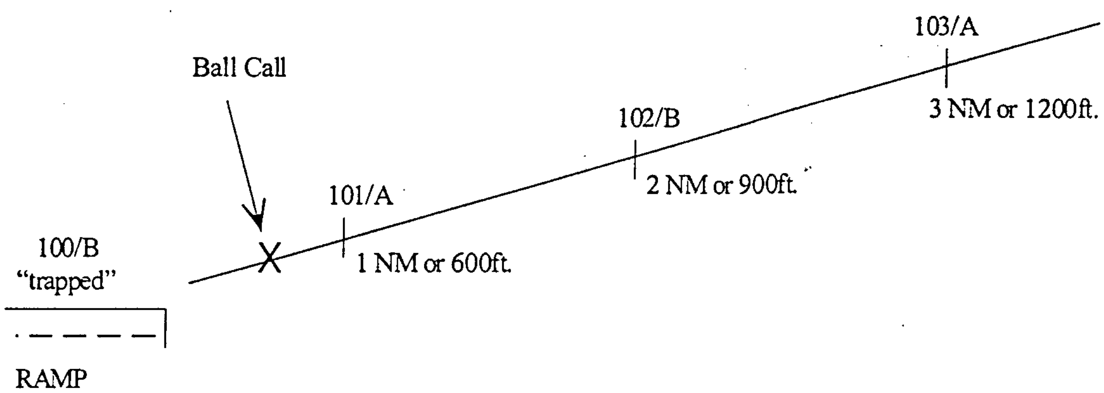
The numbers can be found in certain cells within the DRTs in Appendix A. To save room in the tables we have decided to add a description in this section that corresponds to those numbers.

Number	Description
1	Kts: Nautical Miles Per Hour
2	CCA: Carrier Controlled Approach
3	AOA: Angle of Attack
4	CCA calls: If not in EMCON and if aircraft is getting voice command form CATC controller. Also, LSO may not be on pilot's frequency at this point since Case III are DUAL FREQUENCY. For Case III, a different frequency is set for every other aircraft: aircraft 101 is on freq. A, aircraft 102 is on freq. B, aircraft 103 is on freq. A, etc...
5	Approach light on and steady means that gear is down. Approach light steady means that hook is down. Approach light flashing means hook is up. However, at night, if one of the three approach lights (red = fast, amber = on speed, green = slow) are burned out, and this is the light that should be illuminated given the aircraft speed at the time, then the appearance will be that the gear are up (e.g., no approach light). In this case the LSO will ask the pilot to "show me as FAST", "show me as SLOW", or "show me as an APPROACH light." The pilot will momentarily dip his nose or pull up slightly in order to get the AOA to change enough to illuminate one of the other two lights to confirm gear down. If no lights working, a W/O is required with a fly by to confirm gear down or not.
6	Discrimination ability: Case I and II - Line up at the 135E position (e.g. rate of turn which results in a line up outcome) is a function of perceiving rate of turn, ship's track, relative wind and turn rate corrections by the pilot. At this point little attention and little LSO input can be made. Discrimination is gross and difficult to quantify.
7	Fpm: feet per mile
8	At 1 NM, if visibility permits, pilots will begin seeing the ball and visual line up cues. Most will include this information in their scan of instruments. This is a critical time for pilots in that most will perceive themselves as high on the G/S at this "first look" at the ship and tend to settle below the G/S. Difficult for the pilot to see anything at 1 NM.
9	At 1 NM last aircraft should have trapped and next aircraft will be on the LSO's frequency and HUD display.
10	The difference between discrimination ability is a function of perceptive ability primarily at night.
11	Case I and II for Attitude/Speed: At the 90E, pilot will see the result of his/her approach turn from 180Eto the 90E and will make most of the major roll corrections from the 90E to X. These changes in AOB require A/S changes to maintain on speed. These changes are difficult to accurately see.
12	Case III for Attitude/Speed: In addition to simply fast or slow, and more critical, is the circumstances of a pilot who has not been able to resolve his speed after 2 miles of descent on the G/S. Average performance is consistently a little fast, poor is > 8 kts fast, consistently slow or unstable slow to on speed to fast to on speed to slow equals lots of problems.
13	Case I and II for Line up at 90E: A turn requiring > 45E AOB is difficult at best. However, a shallow turn of < 15E AOB will necessitate a rapid increase to over 45E AOB to stop the aircraft on the C/L at the X and is therefore a more critical error/correction association.
14	G/S &G/P all cases: Although a nose down (ND) action by the pilot would appear to be an A/S correction, IM - AR is a quick G/P correction to increase ROD. In fact, it's quicker than waiting for a power reduction to affect sink rate. Improper, but not uncommon, it is somewhat acceptable but can have disastrous consequences if not properly executed and corrected.
15	All specific cues are amplified by aircrafts relative size and peripheral environment from IM - AR.

16	However, very rare since aircraft are in level flight prior to G/S intercept at 200 ft. This is basic instrument flying at this point.

Additional Notes

< Case I and II use primary frequency A. Case III uses dual frequency.



The controller is talking to 101/A and 103/A. When ball is called, controller stops talking to 103/A for about 20 seconds, and the LSO does not stop talking. Before this, LSO gets G/S information from the controller's calls.

- The new guy is easiest to control because of heightened expectation of problem.
- For estimation of airspeed, actual perception is the ***degree of attitude***, which translates to kts.
- HUD not available @ 2 NM. Only when aircraft is IC - 1 NM (unless 1st aircraft is in).
- At the 90E, G/S, attitude and L/U are starting to get more and more "mashed" together.
- ND will cause a settle and this is want we want to avoid.
- Notice that as pilots get closer to the ramp, the Top pilot has a possible - probable problem IC-AR. The reason for this is because LSO doesn't expect Top pilot to be out of parameters here. If he is, he may have more problems. If Top guy has problems here, he becomes more like the FNG.
- No approach light check required during daytime because LSO can get a visual.

Appendix C: SPN46 Track Data

Header Contains:

Label	Pass Number	Channel	Acft Side No.	Time (hh:mm:ss)
RECORD	00056	A	105	15:41:14

DATA CONTAINS:

TIME (mm:ss) since lockon	X position (ft)	Y position (ft)	Z position (ft)	Ship's pitch (deg)	Ship's roll (deg)	Closing speed (ft/sec)	Sink speed (ft/sec)
00:44.4500	2866	-37.50	220	.27466	.70862	-218	-6.40625

Aircraft Types vs Side Numbers

F-14A	F-14B	F-18	A-6	C-2
101 202 205	210	301 105	520 502	COD

Appendix D: Comment Examples and Explanations

LSO COMMENTS (Grade)	INTERPRETATION
(LOOSX) /CBIM HIC (HCDAR)	Slightly Low, Over Shot at the Start. Flew up through the Glide Path in th Slightly high, come down at the Ramp.
SRD.OSX HSLOIM-IC PNU.CDAR	Stopped Rate of Descent on overshooting the start. High and slow from i Pulled nose up on coming down at the ramp.
OC(S.X) /IM HIC HCDAR	Over control and a little settle on the start. Fly up through glide path in th High and come down at the ramp.
(HX) TMP.CDIM HIC (PNU.CDAR)	Slightly high start. Too much power on come down in the middle. High ir nose up on come down at the ramp.
(LOX) /IM HIC \AR	Slightly low at the start. Fly up through the glide path in the middle. High through the glide path at the ramp.
S.X LOIM NEP.COIC LOAR	Settled on the start. Low in the middle. Not enough power on come on ir
(HX) OCNEP.CDIM HFIC-AR	Slightly high at the start. Over controls and not enough power on coming and fast in close through the ramp.
(HWUX) OC(SIM) (HFIC) (HCDAR)	A little high and wrapped up at the start. Over controls and settles a little and fast in close. Slightly high and comes down at the ramp.
LOLURX NEP.CBIM LOIC LOBAR	Low and lined up right at the start. Not enough power on come down in tl Low and flat at the ramp.
(HX-IM) (TMP.CDIC) (HAR)	A little high from the start to the middle. A little too much power on come high at the ramp.
(LOX) NEP.COIM LOIC LOBAR	A little low at the start. Not enough power on come on in the middle. Lov the ramp.
HAW	High all the way
(LOX) NEP.COIM S.RUFWIC LOAR	A little low at the start. Not enough power on come on in the middle. Set Low at the ramp.
SRD.(LOX) /IM (TMP.CDIC) (HCDAR)	Stopped rate of descent on slight low at the start. Flies up through glide p too much power on come down in close. Slightly high and comes down a
(LOX) /IM _HIC_ HCDAR	A little low at the start. Flies up through the glide path in the middle. Ve comes down at the ramp.
(LOX) /IM HDRIC (\.LUAR)	A little low at the start. Flies up through the glide path in the middle. Higl Slightly flies down through the glide path on lineup at the ramp.
TMP(HX) HIM-IC (HCDAR)	Too much power and slightly high at the start. High in the middle through comes down at the ramp.
(H.OSX) NEP.CBIM \IC LOAR	A little high on overshooting the start. Not enough power on come back (down through glide path in close. Low at the ramp.
OSX TMP.CBIM HIC (HCD.LUAR)	Over shoots the start. Too much power on come back in the middle. Higl comes down on lineup at the ramp
S.LULX (/IM) (HIC-AR)	Settles on lineup left at the start. Flies up a little through the glide path in close to ramp.
(OSX) (TMP.CBIM) (HIC) (HCDAR)	Slightly overshoots the start. A little too much power on come back (lineu high in close. Slightly high and comes down at the ramp
HX-IM NEP.CDIC \AR	High from the start to the middle. Not enough power on come down in clo glide path at the ramp.
OC(TMRDX) (HIM) (HCDIC-AR)	Over controls and has a little too much rate of descent at the start. A bit l high and comes down from in close to the ramp.
(HAA.X) (TMP.CDIM) (HIC) (\AR)	Slightly high, angling approach at the start. A little too much power on co A little high in close. Flies down through glide path at the ramp.
(LOX) TMP.COIM /IC HCD.LUAR	A little low at the start. Too much power on come on in the middle. Flies in close. High, comes down on lineup at the ramp.
(LOX-IM) (/IC) (HAR)	A little low from the start to the middle. Flies up through glide path in clos
(NESA) (HIM) HIC (\AR)	Not quite enough straight away. A little high in the middle. High in close. Flie glide path at the ramp.

HCDX OC(NEP.CDIM) HIC HBAR	High, comes down at the start. Over controls but not quite enough power on th High in close. High and flat at the ramp.
TMPIM HIC HCDAR	Too much power in the middle. High in close. High, come down at the ramp.
SRD.X HBIM-IC HAR	Stopped rate of descent on the start. High, flat in the middle to in close. High a
(SIM) (/IC) (HAR)	Settled a little in the middle. Flew a little up through the glide path in close. A
(H)DL.X OCTMP.LUIM \.LUIC LOAR	A little high and drifted left on the start. Over control with too much power on down through glide path on the line up in close. Low at the ramp.
(HX-IM) TMPIC HBAR	Slightly high from at the start to in the middle. Too much power in close. High
OC(HIM) (\.LUIC) (LOBAR)	Over controls and slightly high in the middle. Flies a little down through the gl A little low and flat at the ramp.
(NEP.LUIM) (LOBIC-AR)	Not quite enough power on line up in the middle. A little low and flat from in c
(SRDIM) OC(HIC) (\AR)	Stopped rate of descent (a little?) in the middle. Over controlled and slightly hi down through the glide path at the ramp.
SRD.X HIM TMP.CDIC HBAR	Stopped rate of descent on the start. High in the middle. Too much power on c flat at the ramp.
SRD.X HIM NEP.CDIC \AR	Stopped rate of descent on the start. High in the middle. Not enough power on down through the glide path at the ramp.
LIG H.OSX-IM (NEP.CDIC) (\AR)	Long in the groove (wings level & in the groove at 22 seconds or more out). H start to the middle. Not quite enough power on come down in close. Flies a litt path at the ramp.
(LOX-IM) NEP.DLIC LOLULAR	A little low from the start to the middle. Not enough power on the drift left in c the ramp.
LIG LO90-X (/IM) (\IC) (LOAR)	Long in the groove. Low from the 90 to the start. Flies a bit up through glide p down through the glide path in close. Low and flat at the ramp.
(HX) OC(TMP.CDIM) \IC LOBAR	A little high at the start. Over controls and has a little too much power on come down through glide path in close. Low and flat at the ramp.
(HX) (OSX) NEP.RTLIM LOIC LOBAR	A little high at the start. Over shoots the start a little. (Note, probably could hav rather than 2 separate entries). Not enough power on the right to left in the mid flat at the ramp.
(LIG) TMP(WUX) HIM-IC HCDAR	A little long in the groove. Too much power and a little wrapped up at the start. in close. High, comes down at the ramp.
(HX) (\IM) (LOBIC-AR)	A little high at the start. Flies a little down through the glide path in the middle. close to the ramp.
(LOX) /IM HCDIC	A little low at the start. Flies up through the glide path in the middle. High and
(HX) (TMP.CDIM) (HCDIC-AR)	A little high at the start. A little too much power on come down in the middle. down from in close to the ramp.
TMP.(HX) HIM HCDIC-AR	Too much power on slightly high start. High in middle. High, come down fron
(TMP.X) (HIM) TMP.CDIC HAR	Little too much power on the start. Little high in the middle. Too much power High at the ramp.
HOOT \.X (TMP.COIM) OC(/IC) (LOAR)	High out of the turn. Fly down through the glide path on the start. Little too mu middle. Over correct, fligh a little up through the glide path in close. A little lo
S.X NEP.COIM LODLIC LOB.LUAR	Settle on the start. Not enough power on the come on in the middle. Low and d on lineup at the ramp.
(TMP.X) (HIM) TMP.CDIC HBAR	A little too much power at the start. Little high in the middle. Too much power High and flat at ramp.
HX TMP.DLIM _H_LULIC HFAR	High at the start. Too much power on drift left in the middle. Very high and li flat on lineup at ramp.
OC(NEPIM) /IC HCDAR	Over control and not quite enough power in the middle. Fly up through glide pa down at ramp.
H(LULX) TMP.LULIM HIC (HCDAR)	High and a little lined up left at the start. Too much power on lineup left in the little high, come down at ramp.
SRD.X HFIM TMP.CDIC HCDAR	Stopped rate of descent on start. High & fast in the middle. Too much power o come down at ramp.
HFOSX OCTMPCBIM F\IC F(LO)AR	High & fast, over shoot the start. Over control, too much power and come back through glide path in close. Fast, slightly low at the ramp.

NESA TMRDOT \X LOIM ND/IC FBAR	Not enough straight away. Too much rate of descent out of the turn. Fly down start. Low in the middle. Nose down, fly up through the glide path in close. Fa
NEP(LOX) LOSLOIM	Not enough power and slightly low at the start Very low and slow in the middle
LIG (LOX) /IM OCHIC \AR LL	Long in the groove. Slightly low at the start. Fly up through the glide path in tl high in close. Fly down through the glide path at the ramp. Land Left.
SRDX HIM DEC.CDIC \AR	Stopped rate of descent at the start. High in the middle Decelerate on coming d through glide slope at the ramp.
(NESA) (HIM) NEP.CDIC LOBAR	Not quite enough straight away. A little high in the middle. Not enough power and flat at the ramp.
(LIG) (H)OSX TMP.CBIM HIC-AR	A little long in the groove. A little high and then overshot the start. Too much p middle. High from in close to at the ramp.
LOOT (LOLULX-IM) (/IC) (HCDAR)	Left out of the turn. A little Low and lined up a little left from the start to in the through the glide path in close. A little high, come down at the ramp.
(TMP.X) (HIM-IC)	A little too much power on the start. A little high from in the middle to in close
(HX) _NEPCDIM_ LOCHLUIC-AR	Little high at the start. Not nearly enough power, come down in the middle. Lo close to at the ramp.
SRD.X HIM-IC HCDAR	Stopped rate of descent on start. High from in the middle to in close. High, cor
(SX) OC(LOIM) HIC-AR	Settle a little at the start. Over control, a little low in the middle. High from in c
(TMRDX) NEPLOIM LOIC	A little too much rate of descent at the start. Not nearly enough power, low in tl
LOX (/IM) (HIC) (HCDAR)	Low at the start. Fly a little up through glide path in the middle. A little high in down at the ramp.
(LOOSX) /IM HCDIC PNU.CDAR	A little low and overshoot the start. Fly a little up through the glide path in the i close. Pull nose up on come down at the ramp.
LOOSX /.CBIM HIC \AR	Low and overshoot the start. Fly up through the glide path and come back in th down through glide path at the ramp.
TMP.OSX HIM PNU.HIC SLO.CDAR	Too much power on overshooting the start. High in the middle. Pull nose up or down at the ramp.
(/.OSX) TMP.CBIM HIC (HCDAR)	Fly a little up through glide path on overshooting the start. Too much power on High in close. A little high, come down at the ramp.
OSX TMP.DLIM HIC-AR	Overshoot the start. Too much power on drift left in the middle. High from in c
(HWUX) TMP.LUIM HIC-AR CDTL	A little high, wrapped up at the start. Too much power on line up in the middle. ramp. Coming down to land.
(LO)OSX /.CBIM HDLIC (\.LUAR)	A little low, and overshoot the start. Fly up through glide path on come back in center. A little fly down though glide path on lineup at ramp.
HOSX TMP.DLIM HLULIC HCD.LUAR	High, overshoot start. Too much power on drift left in middle. High, lineup lef on lineup at the ramp.
SRD.(OSX) HDLIM HLULIC HCD.LUAR	Stopped rate of descent. Slightly overshoot the start. High, drift left in the midc High, come down on lineup at the ramp.
OC(S.X) (/IM) (DR.CDIC) (\.LUAR)	Over control and slight settle on the start. Fly up through glide path a little in the come down in center. Fly a little down through glide path on lineup at the ramp
(HX) NEP.CDIM LOBIC-AR	A little high at the start. Not enough power on come down in the middle. Low the ramp.
(LOX) (/DRIM) (HIC) (CD.LUAR)	A little low at the start. Fly a little up through the glide path and drift right in th close. Slight come down on lineup at the ramp.
(LO)OSX (TMP.CBIM) (HIC) (HCDAR)	A little low and overshoot the start. A little too much power on come back in th close. A little high, come down at the ramp.
S.X LOIM /IC HCDAR	Settle at the start. Low in the middle. Climb up through the glide path in close. ramp.
(LO)OSX LURIM (NEP.CDIC) (CD.LUAR)	A little low and overshoot the start. Lineup right in the middle. Not quite enou in close. A slight come down on lineup at the ramp.
(LIG) (NEPIC) (LOAR)	A bit Long in the groove. Not quite enough power in close. A little low at the r
(OSX) (H.CBIM) (NEP.CDIC) (LOAR)	Slightly overshoot the start. A little high on come back in middle. Not quite en close. A little low at the ramp.
(LOOSX) OCNEP.CBIM HIC HCDAR	Slightly low and overshoot the start. Over control, not enough power on come b close. High, come down at ramp.

HOOT-X (HIM) (HCDIC-AR)	High out of the turn to the start. Slightly high in the middle. Slightly high ar the ramp.
LOOSX /.CBIM HBIC-AR	Low and over shoot the start. Fly up through glide path on come back in mid to the ramp.
(LURX) (TMPIM) (HIC) (HCDAR)	A little lined up right at the start. A little too much power in the middle. A li come down at the ramp.
SRDIM HIC-AR	Stopped rate of descent in the middle. High from in close to at the ramp.
HWUX TMP.CDIM HIC HBAR	High and wrapped up at the start. Too much power on dome down in the mi flat at the ramp.
(LURX) (NEP.LUIM) (SIC) (LOBAR)	A little lined up right at the start. Not quite enough power on line up in the m little low and flat at the ramp.

HOOT-X (HIM) (HCDIC-AR)	High out of the turn to the start. Slightly high in the middle. Slightly high and (the ramp.
-OOSX /.CBIM HBIC-AR	Low and over shoot the start. Fly up through glide path on come back in middl to the ramp.
-URX) (TMPIM) (HIC) (HCDAR)	A little lined up right at the start. A little too much power in the middle. A littl come down at the ramp.
DIM HIC-AR	Stopped rate of descent in the middle. High from in close to at the ramp.
'UX TMP.CDIM HIC HBAR	High and wrapped up at the start. Too much power on dome down in the midd flat at the ramp.
RX) (NEP.LUIM) (SIC) (LOBAR)	A little lined up right at the start. Not quite enough power on line up in the mid little low and flat at the ramp.

Appendix E: Landing Profile

SQUADRON VF-103 LANDING PROBLEM PROFILE AIRCRAFT : ALL
RECOVERY PERIOD 8/19/1995 11:15:00 PM - 10/20/1997 12:30:00 PM DAY/NITE/ALL A
PILOT SELECTED DOMINO MOVLAS : A

	GLIDESLOPE HI	GLIDESLOPE LO	DESCENT RATE TM	DESCENT RATE NE	SPEED FAST	SPEED SLOW	POWER (+)	POWER (-)	ATTIT.	LINEUP + WING
AW										
X		======	======							######
		======	======							######
IM	======									######
	======									######
IC	======									
	======									
AR	======	======	======							
	======	======	======							
TL										

TOTAL NUMBER OF APPROACHES = 4

LEGEND: HIGH ######
MEDIUM ======
LOW ------

Appendix F: Deviations Table

Deviations Table	Acceptable, little or no correction needed	Reasonable, correction will be needed	Gross Deviation
1 Mile			
High (ft)	No Limit	No limit	No limit
Low (ft)	25	50	100
Fast (nmph)	5	10	20
Slow (nmph)	5	10	20
Left (ft)	> 37.5	>75	>150
Right (ft)	> 37.5	>75	>150
¾ Mile (near the Start "X"			
High (ft)	25	50	
Low (ft)	12.5	25	
Fast (nmph)	5 (Case 1 & 2) 2.5 (Case 3)	10 (Case 1 & 2) 5 (Case 3)	20 (Case 1 & 2) 10 (Case 3)
Slow (nmph)	2.5	5	10
Left (ft)	37.5	75	150
Right (ft)	37.5	75	150
¼-1/2 Mile (In Middle "IM")			
High (ft)	20	40	80
Low (ft)	10	20	40
Fast (nmph)	5	10	20
Slow (nmph)	2.5	5	10
Left (ft)	25	50 Case 1) 50+ (Case 2 & 3)	100
Right (ft)	25	50 Case 1) 50+ (Case 2 & 3)	100
1/8 Mile (In Close "IC")			
High (ft)	10	20	40
Low (ft)	5	10	20
Fast (nmph)	2.5	5 or >5 change	10
Slow (nmph)	2.5	5 or > 5 change	10
Left (ft)	12.5	25 or >5° AOB	50
Right (ft)	12.5	25 or >5° AOB	50
At the Ramp ("AR")			
High (ft)	5	10 or >200fpm ROD off ideal	20
Low (ft)	2.5	5 or >200fpm ROD off ideal	10
Fast (nmph)	>1.5° pitch	>3° pitch	>6° pitch
Slow (nmph)	>1.5° pitch	>3° pitch	>6° pitch
Left (ft)	7.5 or >1.5° AOB	15 or >3° AOB	30
Right (ft)	7.5 or >1.5° AOB	15 or >3° AOB	30

AOB = Angle of Bank ROD = Rate of Descent

Appendix G: Summary of Variables and Formula

riables	units	interpretation
x	ft.	the x position of the aircraft
y	ft.	the y position of the aircraft
z	ft.	the z position of the aircraft
closing speed	ft/sec	dx/dt, the rate of change of x with respect to time
sink rate	ft/sec	dz/dt, the rate of change of z with respect to time
lineup	ft.	This is the deviation of the y-coordinate of the aircraft from the actual centerline reference for the landing (angled) deck
glideslope	deg.	$\tan^{-1}(z/x)$, nominal glideslope is 3.5°
1 NM	mile	1 mile from the ramp of the ship
X (The Start)		approximately 1/2~ 3/4 mile from the ramp of the ship
IM(In the Middle)		approximately 1/4 mile from the ramp of the ship
IC(In Close)		approximately 1/8 mile from the ramp of the ship
AR(At the Ramp)		right at the ramp (stern of the ship)


CAG